British Geological Survey

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Overseas Geology Series

The hydrogeology of the Oju/Obi area, eastern Nigeria: Oyinyi Iyechi area data report

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Borehole development, borehole BGS20 at Oyinyi Iyechi.

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CONTENTS

List of Tables

List of Figures

List of Annexes

PREFACE

Oju is a remote part of south-eastern Nigeria that suffers from severe water shortage during the annual dry season. From November to April, unprotected ponds, seepages and hollows are the primary source of domestic water. Unfortunately, these sources become less reliable towards the end of the dry season and many are contaminated. As a consequence, much of the population of Oju (300 000 approx.) is badly affected by a variety of water related illnesses, of which guinea worm and malaria are endemic; outbreaks of cholera, typhoid and dysentery are also common. In response, DFID have commissioned WaterAid to provide improved village level, year round water sources, primarily utilising the limited groundwater resources of the area.

Due to the complex hydrogeology, WaterAid have asked the British Geological Survey (BGS) to assist with the project. BGS are applying the results of TDR projects undertaken within other parts of the world to study these marginal groundwater resources.

The groundwater investigations by BGS started in September 1996. There are three main aims of the research: (1) to assess the potential of the Oju area for sustainable groundwater supplies; (2) to develop appropriate methods for siting wells or boreholes in the Oju environment; and (3) to recommend appropriate methods and designs for exploiting groundwater.

This report forms one of a series of data reports designed to complement the summary assessment of the hydrogeology of the Oju/Obi area and the Groundwater Development Map. The data presented were collected on five separate trips, August-September 1996, November-December 1996, February-March 1997, October-December 1997 and January-April 1998.

EXECUTIVE SUMMARY

The groundwater potential of the metamorphosed Asu River Group shales where interbedded with igneous rocks of the Abakaliki Pyroclastics was investigated at Oyinyi Iyechi. Investigations, that included 3 km of EM34-3 and magnetic traverses as well as three resistivity soundings, were carried out between February and March 1998. Three boreholes were drilled; rock chip and core samples were analysed and logged. BGS19, BGS20 and BGS21 were completed as production boreholes with screen and casing. Each borehole was test pumped and water samples obtained for hydrochemical analysis. The following conclusions can be made from the test site.

- The metamorphosed Asu River Group rocks present include meta-sandstones, limestones and mudstones with interbedded blocky ash layers and intrusions of dolerite and gabbro. Much iron pyrite was found mainly disseminated within the sandstone layers. The hard mudstones had a slatey cleavage.

- The rocks are highly fractured and many of the fractures are filled with calcite and some with quartz.

- Significant quantities of groundwater was found within the fracture systems of the metamorphosed Asu River Group – the highest yields were associated with weathered ash layers in BGS20.

- EM34-3 readings were generally low (0-30 mmhos/m) reflecting the low kaoline/illite clay content of the rock.

- Low electrical conductivity (high resistivity) and magnetic anomalies are indicative of pyroclastic rocks or highly metamorphosed mudstones close to the surface.

- The highly variable horizontal coil readings appear to indicate the presence of fractures.

- The groundwater quality found within the metamorphosed Asu River Group was good.

1. BACKGROUND INFORMATION

The groundwater potential of the metamorphosed Asu River Group was tested at Oyinyi Iyechi. The village is located on the southern flank of the Wokum Hills (see Figure 1). There are no wells within the village. During the wet season community members take their water from the several streams that flow through the village. When the streams stop flowing in the dry season, water is obtained from springs located in the hills; but by March even these springs are dry and community members are forced to walk to Oju Barracks for water.

The geology map indicates that the village is located near the boundary between the Asu River Group and the metamorphosed Asu River Group. The Asu River Group is composed of a series of hard shaley mudstones and sandstones deposited under deep water marine conditions during the Middle to Upper Albian part of the Cretaceous period. These sediments have undergone low-grade metamorphism due to the effects of burial diagenesis that has resulted in the lithification and fracturing of the strata (Davies and MacDonald 1998). Within the central part of the basin of deposition these sediments were interbedded with intrusive and extrusive igneous rocks of the Abakaliki Pyroclastics Formation. Additional local contact metamorphism of the shaley mudstones resulted where they were in contact with the igneous intrusive rocks, these harder more metamorphosed sediments and associated igneous rocks now forming the core of the Wokum Hills. The occurrence of surface exposures of igneous rocks, some very coarse grained, and interbedded ash deposits within one of the exploration boreholes drilled indicate that the village is underlain by metamorphosed Asu River Group rocks. Figures 2 and 3 show the available map data for the area and also the location of the geophysics surveys and test boreholes. Table 1 shows the appropriate maps and aerial photographs for Oyinyi Iyechi.

Table 1. Available map information for Oyinyi Iyechi.

Data type	Source
Aerial Photographs	Sheet 289, run 5, 202-204 Sheet 289, run 6, 151-154
Topographic maps	1:50,000 Sheet 289NE Ejekwe NE
Geology map	Ogoja Area, Map No. 73, Scale 1:250,000

2. GEOPHYSICS

Three kilometres of EM34-3 surveys were carried out within the village of Oyinyi Iyechi. Both horizontal and vertical dipole measurements were taken, all with an inter-coil spacing of 20 m. Magnetic field surveys were also carried out along most of the EM34-3 traverses. Vertical electric soundings (VES) were carried out at several locations. Table 2 gives a summary of the various traverses and soundings undertaken. Geophysical traverse data are presented in Appendix 1.

The EM34-3 data recorded were highly variable; vertical coil (horizontal dipole) measurements ranged from 0 to 30 mmhos/m whereas although horizontal coil (vertical dipole) measurements were generally similar to the vertical coil readings, they were much noisier with several striking anomalies. Figure 4 shows the EM34-3 and magnetic data for OY1, OY2 and OY4. The surveys divided into three categories:

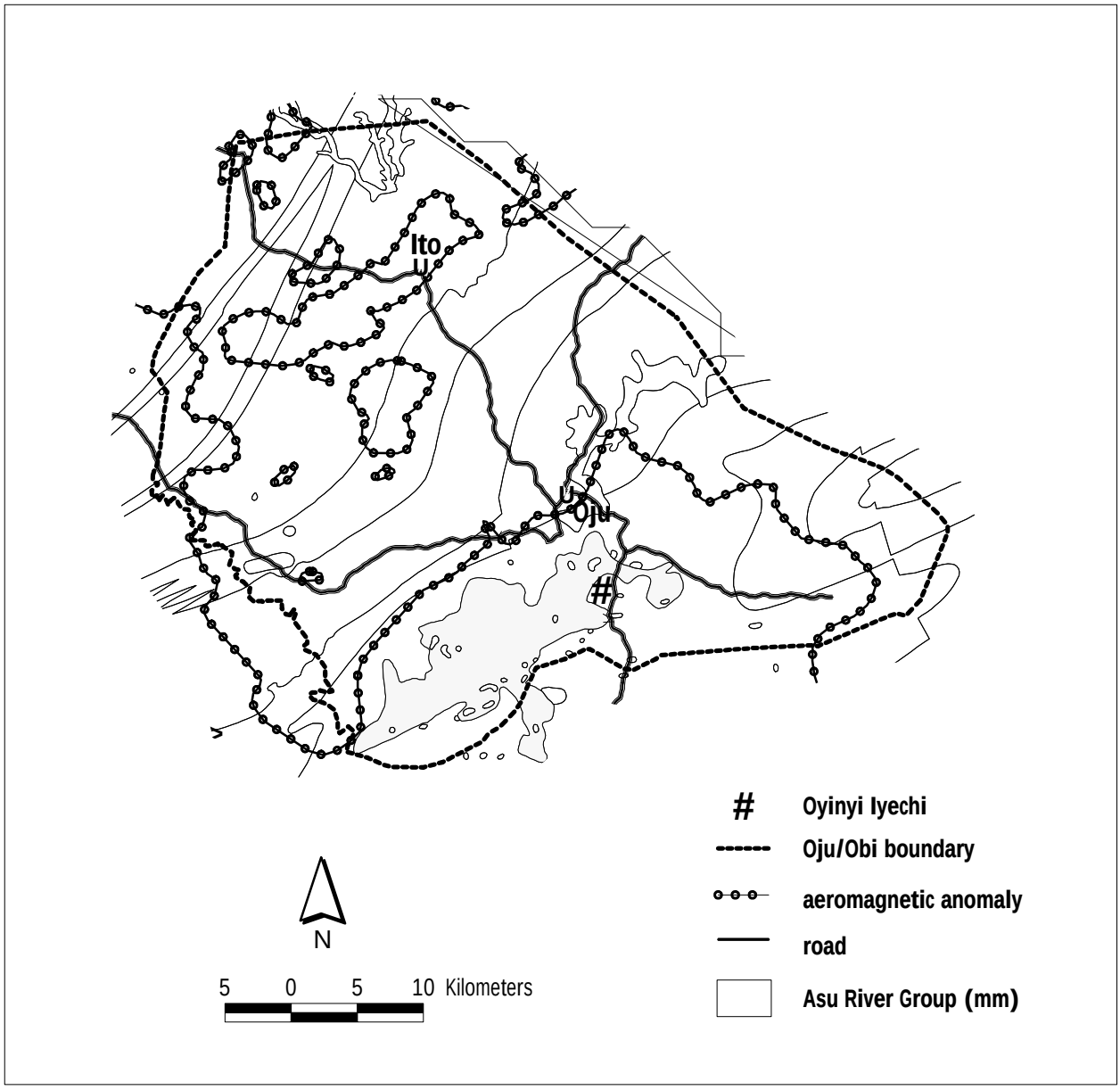

Figure 1. Location of Oyinyi Iyechi and outcrop of the metamorphosed Asu River Group.

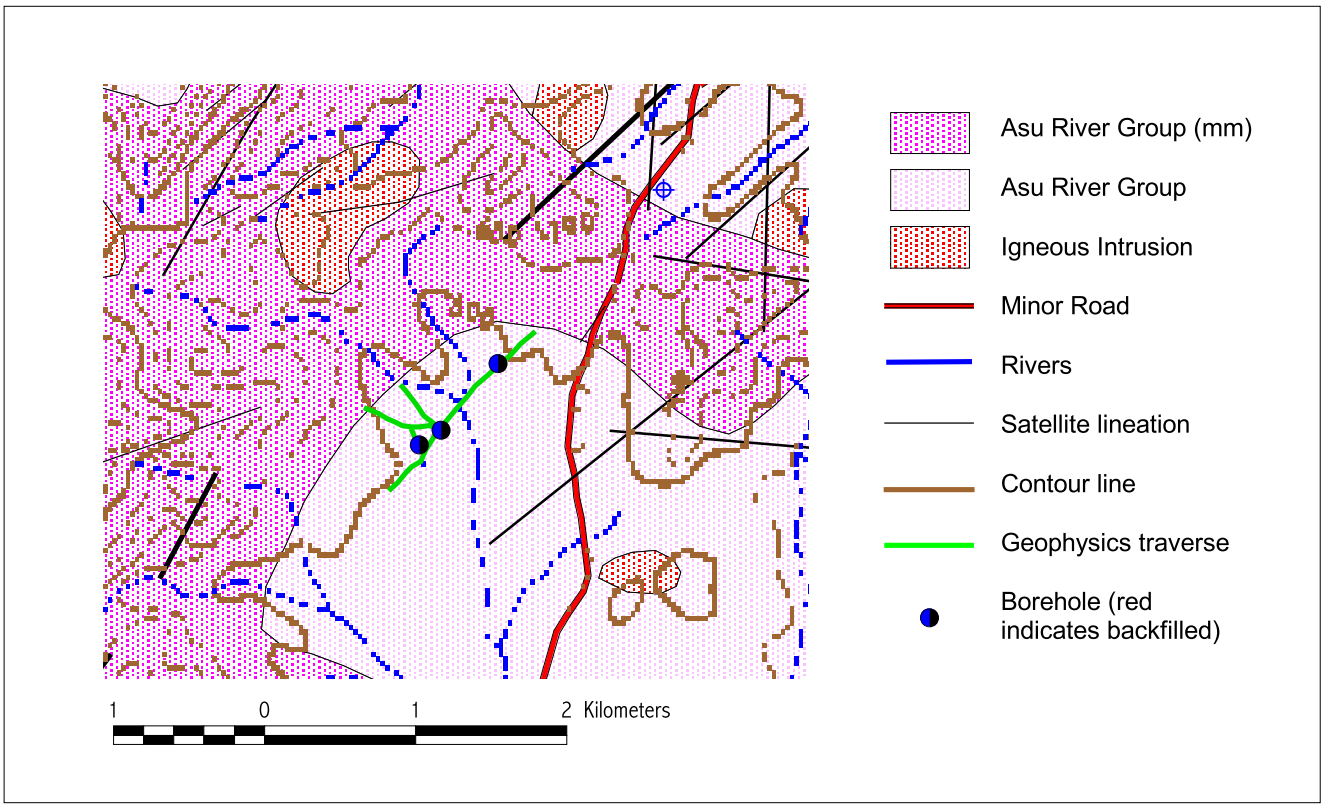

Figure 2. Available map information for Oyinyi Iyechi, and location of boreholes and geophysical surveys.

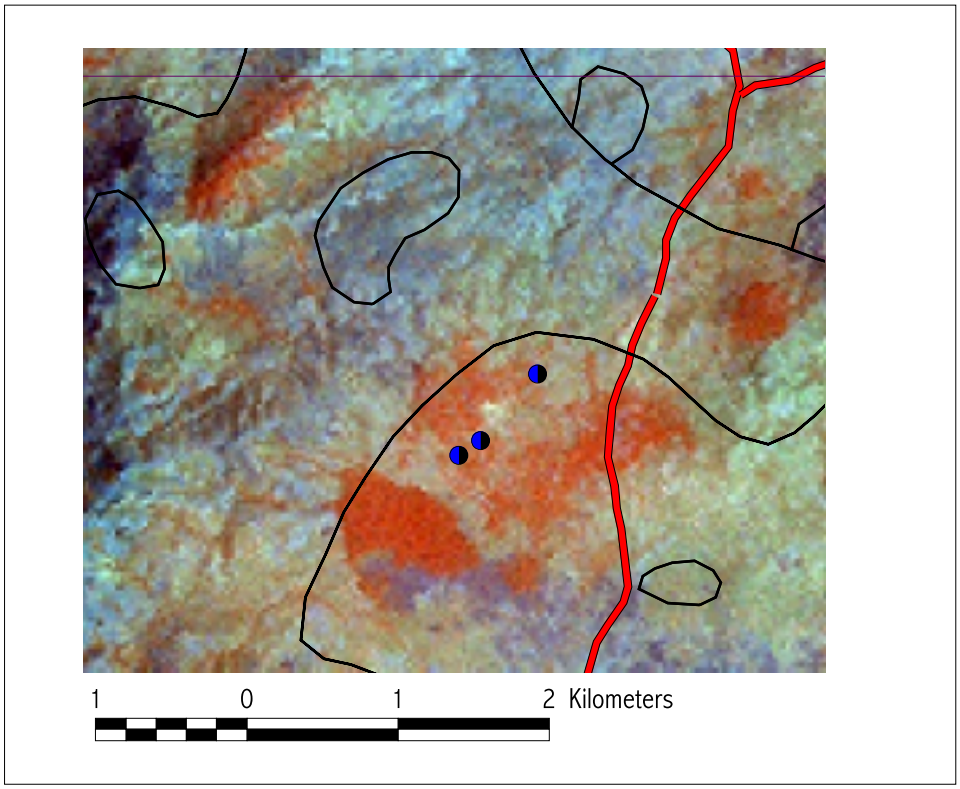

Figure 3. Satellite image for Oyinyi Iyechi.

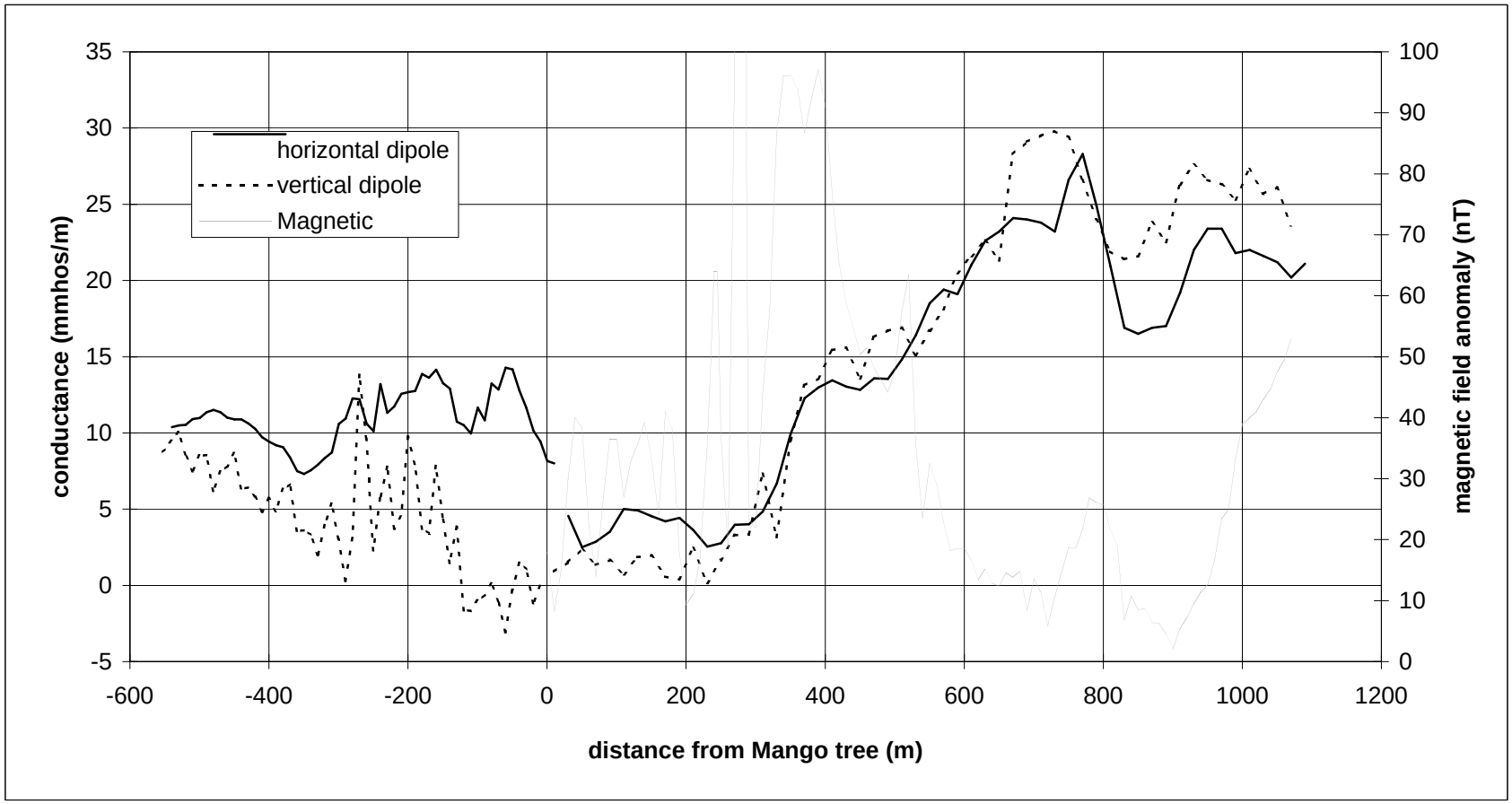

Figure 4 EM34-3 and magnetic data along OY1 and OY2 at Oyinyi Iyechi. Boreholes were located at about -200 m, 120 m and 600 m.

- Where both vertical and horizontal coil readings are low (less than 5 mmhos/m)
- Where vertical coil readings are about 10 mmhos/m with "noisy" horizontal coil readings
- Where both vertical and horizontal coil readings are high – horizontal coil generally higher than vertical coil.

The magnetic surveys indicated the presence of strata containing much magnetic material. Where the EM34-3 readings were low and noisy, there were many short wave length magnetic anomalies. As the EM34-3 readings rose, the magnetic profile became less noisy and anomalies had a longer wavelength.

Table 2. Main Geophysical Surveys carried out at Oyinyi Iyechi (data in Annex 1).

Survey number	Co-ordinates start	Length	Average Spacing	Survey type	Description
OY1	6 ° 48.811' 8° 26.930'	0.5 km	10 m	EM34-3 (20 m)	From mango tree at School across stream to AoG church
OY2	6 ° 48.811' 8° 26.930'	1.1 km	20 m	EM34-3 (20 m)	From Mango tree at School back along road
OY3		0.4 km	20 m	EM34-3 (20 m)	From 120 m along OY2 up to playground
OY4	6 ° 48.811' 8° 26.930'	1.1 km	10 m	magnetic	As OY2
OY5		0.4 km	10 m	magnetic	As OY3
OY6		0.5 km	20 m	EM34-3 (20 m)	From 40 m along OY3 passed school to playground
OY7		0.3 km	20 m	EM34-3 (20 m)	From stream on OY6 to cross roads on OY1
OY8	6° 48.811 8° 26.930		0.5 – 64 m	Offset Wenner	100 m along OY2 (BGS19)
OY9			0.5 – 64 m	Offset Wenner	Located on junction at 120 m along OY1 (BGS20)
OY10			0.5 – 64 m	Offset Wenner	Located 600 m along OY2 (BGS21)

Three resistivity surveys were carried out at the village: one on each of the three different EM34 responses seen above. OY8, located on the very low EM34 –3 readings showed a resistive soil followed by ten metres of moderate resistivity with high resistivity at depth. OY9 was located on the very noisy EM response and showed a resistive soil followed by five metres of low resistivity and infinitely resistive bedrock. OY10, located on the higher EM34-3 readings, showed a resistive soil followed by a very thick low resistivity layer (50 ohm-m) with an indication of higher resistivity at about 40 m depth.

A test borehole was located close to each of the resistivity depth probe sites:

- BGS19: in playing field 100 m along OY2
- BGS20: 150 m along OY7 – close to junction on OY2
- BGS21: at road junction - 600 m along OY2.

3. DRILLING

Three boreholes were drilled at Oyinyi Iyechi. The boreholes were drilled with tricone through the overburden and hammer through the competent rock; representative 3m core samples were taken where possible. Summary information on the boreholes is given in Table 3. Details of drilling and construction are given in Annex 2.

Table 3. Summary details of drilling. Full details given in Annex 2

Borehole ID	Location	Date completed	Total depth	Drilled diameter	Section cored	Main water strikes	Casing above gl	Comments
BGS19	6° 48.809' 8° 26.954'	10/2/98	41.5 m	165 mm	38.5 – 41.5 m	14.5 m 24 m	0.6 m	
BGS20	6° 48.279' 8° 26.899'	12/2/98	41 m	165 mm	38 – 41 m	15 m 36.5 m	0.25 m	Much water
BGS21	6° 48.990' 8° 27.173'	13/2/98	38.5 m	165 mm	No core	11.5, 15, 19 m	0.5 m	

Summary lithological logs for each of the boreholes drilled are given below. Detailed lithological logs are given in Annex 3. Figure 5 shows a schematic of the borehole logs.

Summary lithological log: BGS 19

0.0 - 1.5	Soil/ferricrete horizon
1.5 - 4.0	Clayey very weathered horizon
4.0 - 5.5	Very weathered shales and clay
5.5 - 7.0	Weathered shaley mudstones
7.0 - 8.5	Fairly weathered shaley mudstones
8.5 - 10.5	Dolerite
10.5 - 14.5	Interbedded hard fine to coarse grained meta-quartzite and slatey siltstones, some vein quartz
14.5 - 16.5	Interbedded hard fine to coarse grained meta-quartzite with slatey siltstones and shaley mudstones, disseminated copper and iron pyrite
16.5 - 18.5	Blocky to slatey calcareous mudstones and limestones with iron pyrite, copper pyrite and thin quartzite
18.5 - 19.5	Shaley to slatey calcareous mudstones
19.5 - 21.5	Slatey and shaley mudstones with hard thin quartzitic fine grained sandstone layers
21.5 - 22.5	Slatey calcareous mudstones interbedded with medium to coarse grained meta-sandstones, some pyrite
22.5 - 23.5	Medium to coarse grained meta-sandstones with slatey mudstones, some pyrite
23.5 - 24.5	Calcareous blocky to slatey mudstones with interbedded fine to medium grained meta-sandstones, some disseminated pyrite
24.5 - 26.5	Blocky to shaley and slatey mudstones
26.5 - 29.0	Slatey and shaley mudstones, fine to medium grained sandstones, disseminated pyrite and vein calcite, with very weathered horizon with kaolin clay
29.0 - 31.0	Slatey and shaley mudstones with disseminated pyrite and vein calcite
31.0 - 32.5	Slatey and shaley mudstones with fine grained sandstones, disseminated pyrite and vein calcite
32.5 - 33.5	Medium grained sandstone with hard slatey mudstones, some pyrite and vein calcite
33.5 - 35.0	Slatey and shaley mudstones with pyrite and vein calcite
35.0 - 37.5	Soft shaley mudstone with pyrite
37.50 – 41.35	Slatey mudstone with hard fine grained sandstone and iron pyrite and calcite

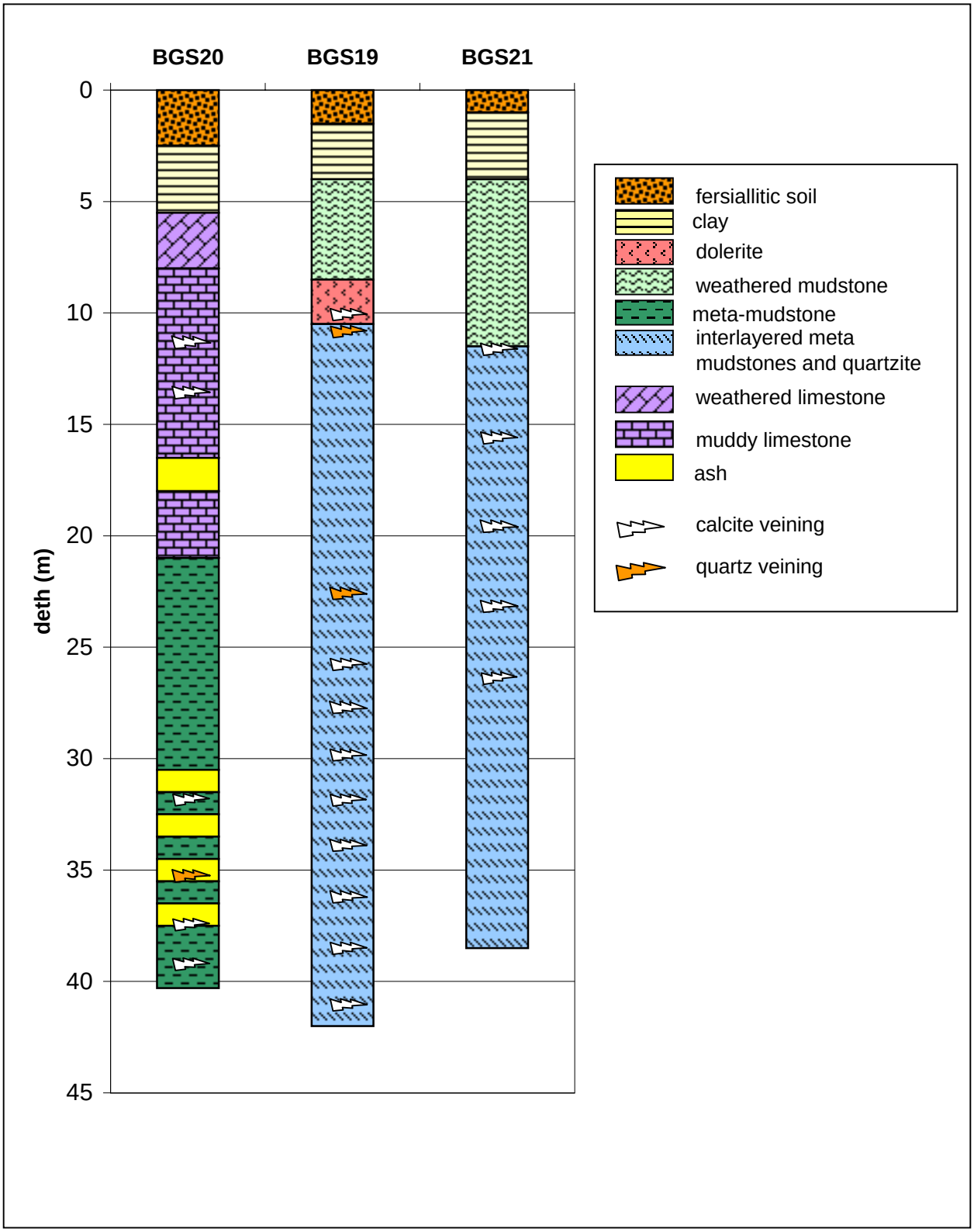

Figure 5. Simplified lithological logs for Oyinyi Iyechi boreholes. (Horizontal axis not to scale).

Summary lithological log: BGS 20

0.0 - 2.5	Soil/ferricrete horizon
2.5 - 5.5	Clayey very weathered horizon
5.5 - 6.5	Weathered blocky mudstones with clay
6.5 - 8.0	Muddy limestone fairly weathered
8.0 - 11.0	Muddy limestone
11.0 - 13.0	Muddy limestone with shales
13.0 - 15.0	Muddy limestone with vein calcite
15.0 - 16.5	Muddy limestone
16.5 - 19.0	Non-calcareous shales with muddy limestones, some pyrite and weathered ash
19.0 - 21.0	Hard shaley calcareous mudstones and non-calcareous shales with pyrite
21.0 - 24.0	Non-calcareous shaley and slatey mudstone with pyrite
24.0 - 25.0	Shaley and slatey calcareous mudstones with muddy limestone and pyrite
25.0 - 30.0	Shaley and slatey mudstone with pyrite
30.0 - 31.5	Slatey and shaley non-calcareous and calcareous mudstones, some weathered ash
31.5 - 34.5	Shaley calcareous mudstones, some muddy limestone, some weathered ash, pyrite and calcite
34.5 - 35.5	Shaley calcareous mudstones and muddy limestone, much pyrite and weathered ash
35.5 - 38.0	Shaley mudstone and muddy limestone with weathered ash and pyrite
38.00 – 40.14	Siltstone, and hard slatey mudstone with pyrite

Summary Lithological log BGS21

0.0 - 1.0	Soil/ferricrete horizon
1.0 - 2.0	Clayey very weathered horizon
2.0 - 4.0	Very weathered clayey shales
4.0 - 5.5	Fairly weathered carbonaceous shaley mudstone
5.5 - 8.0	Weathered carbonaceous shaley mudstone, some clay
8.0 - 10.5	Fairly weathered carbonaceous shaley mudstone
10.5 - 11.5	Carbonaceous mudstone with interbedded medium to coarse grained muddy sandstone
11.5 - 13.5	Hard coarse grained meta-sandstone with slatey mudstone
13.5 - 15.5	Hard slatey carbonaceous mudstone
15.5 - 18.0	Hard metamorphosed carbonaceous slatey mudstone and siltstone, some medium grained meta-sandstone
18.0 - 20.0	Hard metamorphosed slatey mudstone and siltstone, some chalcopyrite.
20.0 - 21.5	Slatey metamorphosed carbonaceous mudstones interbedded with schistose medium grained meta-sandstone, much disseminated pyrite
21.5 - 22.5	Metamorphosed slatey mudstone and siltstone
22.5 - 25.0	Slatey metamorphosed carbonaceous mudstones interbedded with schistose medium grained meta-sandstone, much disseminated pyrite
25.0 - 28.0	Medium to coarse grained metaquartite with phylitic and slatey mudstones, some disseminated pyrite
28.0 - 30.5	Slatey carbonaceous mudstone interbedded with fine to coarse grained meta-quartzite
30.5 - 32.5	Hard metamorphosed interbedded fine to medium sandstone, siltstone and slate, some chalcopyrite
32.5 - 34.0	Fine to coarse grained meta-sandstone, some slates with pyrite
34.0 - 35.5	Fine to medium grained meta-sandstone, some slates with pyrite
35.5 - 36.5	Medium to coarse grained meta-sandstone with slatey siltston and mudstone

36.5 - 37.5	Fine to medium grained meta-sandstone with slatey mudstone
37.5 - 38.0	Slatey mudstone with fine to coarse grained meta-sandstone
38.0 - 38.5	Metamorphosed siltstone and fine grained sandstone, some chalcopyrite

4. PUMPING TESTS

The three boreholes drilled at Oyinyi Iyechi produced air lift yields of groundwater in excess of 1 l/sec. Bailer tests were carried out on each borehole followed by longer tests using either a Honda centrifugal pump or a Grundfos electrical submersible pump. Two one hour tests were also carried out in each borehole using the Whale pumps. Bailer tests were analysed using a variation of slug test analysis (Barker 1989) and the longer tests with standard pump test analysis (Kruseman and de Ridder 1990). Table 4 gives a summary of the test pumping; data and analyses are given in Annex 4.

Test pumping results obtained from BGS20 indicated that the Asu River group rocks there had the best aquifer properties in the area. BGS19 and 20 showed standard responses to pumping (although there were problems keeping the Grundfos pump at a steady rate for the longer test in BGS19). These two boreholes should be able to sustain a handpump. BGS21 showed a marked increase in drawdown after 70 minutes of pumping. This is probably due to the dewatering of an important fracture zone at about 21 m depth. Therefore, if water supplies are to be sustainable from this borehole, the water level should not be allowed to drop below this important flow horizon. Longer term testing should be carried out in these boreholes and the effect of abstraction upon water-levels need to be monitored if the long term sustainability of the fractured rock aquifers of the area are to be assessed.

Table 4. Summary of pumping tests carried out at Oyinyi Iyechi. (Annex 4 contains data and analyses).

Borehole and Test	Date	Casing (magl)	RWL (mbtc)	Length of test (mins)	P-rate (l/s)	Transmissivity (m^2/d)
BGS19						
Bailer test	18/3/98	0.6 m	7.353 m	9:46 mins	0.3 l/s	Barker: 9.5 m^2/d Theis Rec 5 m^2/d
Whale test 1	18/3/98	0.6 m	7.128 m	60 mins	0.16 l/s	Jacob: 5.4 m^2/d Theis Rec: 4.8 m^2/d
Whale test 2	18/3/98	0.6 m	7.145 m	60 mins	0.26 l/s	Jacob: 6.5 m^2/d Theis Rec: 5 m^2/d
Grundfos	21/3/98	0.6 m	6.51 m	60 mins	1.05 l/s	Theis Rec: 6.5 m^2/d
BGS20						
Bailer test	19/3/98	0.25 m	2.63 m	7:23 mins	0.46 l/s	Barker: 48 m^2/d Theis rec: 52 m^2/d
Whale test 1	19/3/98	0.25 m	2.645 m	60 mins	0.19 l/s	Jacob: 22 m^2/d Theis Rec: 27 m^2/d
Whale test 2	19/3/98	0.25 m	2.695 m	60 mins	0.405 l/s	Jacob: 21 m^2/d Theis Rec: 27 m^2/d
Centrifugal	18/3/98	0.25 m	2.61 m	60 mins	2.9 l/s	Jacob: 44 m^2/d Theis Rec (early) 41 m^2/d Theis rec (late) 18 m^2/d
BGS21						
Bailer test	18/3/98	0.5 m	5.99 m	8:48 mins	0.32 l/s	Barker: 3.7 m^2/d Theis rec: 3.6 m^2/d
Whale test 1	19/3/98	0.5 m	5.983 m	60 mins	0.17 l/s	Jacob: 3.7 m^2/d Theis Rec: 3.5 m^2/d
Whale test 2	19/3/98	0.5 m	6.218 m	60 mins	0.27 l/s	Jacob: 4.1 m^2/d Theis rec: 4.1 m^2/d
Grundfos test	22/3/98	0.5 m	5.66 m	100 mins	0.85 l/s	Jacob (early): 2.7 m^2/d Jacob (late): 0.38 m^2/d Theis rec: 3 m^2/d

A water sample was taken from each of the boreholes. This was taken either during the pumping test or later using the Whale pump. Some field analysis was undertaken (see Table 5) and the samples were also analysed in the UK Hydrochemical analyses of water samples obtained during test pumping and from nearby boreholes are presented in Annex 5. All the samples conform to the WHO standards for drinking water.

Table 5. Chemistry samples taken from Oyinyi Iyechi.

ID No	Sample No	date	Conductivity (? S/cm@25°C)	TDS (mg/l)	pH	Temp (°C)	HCO3 titr (50ml 1.6M)	Comments
BGS19	257	3/4/98	532	266	6.93	29	131	Sample taken after 15 mins pumping with Whale pump
BGS20	220	19/3/98	699	352	7.07	28	168	Sample taken after 30 mins pumping
BGS21	219	19/3/98	588	295	6.68	29	147	Sample taken after 30 mins pumping

5. SUMMARY AND CONCLUSIONS

The groundwater potential of the metamorphosed Asu River Group was investigated at Oyinyi Iyechi in southern Oju. Various geophysical surveys were undertaken and a series of boreholes drilled and tested. The following work was undertaken at Oyinyi Iyechi:

- 3 km of EM34-3 surveys
- 1.5 km magnetic profiling
- 3 resistivity VES
- 3 boreholes were drilled and approximately 3 m of core taken from both BGS19 and BGS20
- chip and core samples from each borehole were logged and analysed
- all boreholes, BGS19, BGS20, BGS21 were screened and cased
- bailer tests and three longer pumping tests were carried out on each borehole
- water samples for hydrochemical analysis were taken from each borehole.

The geophysical surveys highlighted the following:

1. EM34-3 readings were generally low (0-30 mmhos/m) reflecting the lack of clay in the rocks

2. Higher EM34-3 readings were associated with fewer magnetic anomalies and are therefore likely to indicate less metamorphism of the mudstones, lower conductivity indicated high metamorphism and the presence of pyroclastic rocks at shallow depths.

3. Noisy horizontal coil profiles are indicative of fractures.

4. Resistivity soundings (VES) carried out at three sites gave distinct profiles. One located where the conductivity was low (<5 mmhos/m) showed a bedrock of resistivity 900 ohm-m; infinite resistivity at shallow depths was recorded where the horizontal coil readings were very noisy (BGS20) – this location proved to have much groundwater. Low resisitivity bedrock (about 50 ohm-m) was recorded where the EM34-3 measurements were higher.

Analysis of the rock and chip samples and test pumping indicated the following:

- The metamorphosed Asu River Group comprises, meta-sandstones, limestones and mudstones with interbedded blocky ash layers and intrusions of dolerite and gabbro.

- The rocks contain much iron pyrite mainly disseminated within sandstone layers

- The rocks are highly fractured and many of the fractures are filled with calcite and some with quartz.

- A thin fersiallitic soil is developed and beneath that a few metres of clay.

- Much groundwater is associated with the pyroclastic rocks (especially the ash) – the groundwater flows through fractures.

- Transmissivity values of 4 – 40 m^2/d were recorded from test pumping of boreholes BGS19 and BGS20. In borehole BGS21, pumping at 1 l/s for 100 minutes dewatered the main fractures at 21 m depth and caused water-levels to fall rapidly.

The groundwater development potential of the metamorphosed Asu River Group rocks is high. Boreholes should be located on fracture zones within the pyroclastic or highly metamorphosed areas – these can be identified from EM34-3 surveys. The quality of the groundwater is generally good and conforms to the WHO recommended guidelines

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Annex 1: Geophysical data

Oyinyi Iyeche

OY 1-3

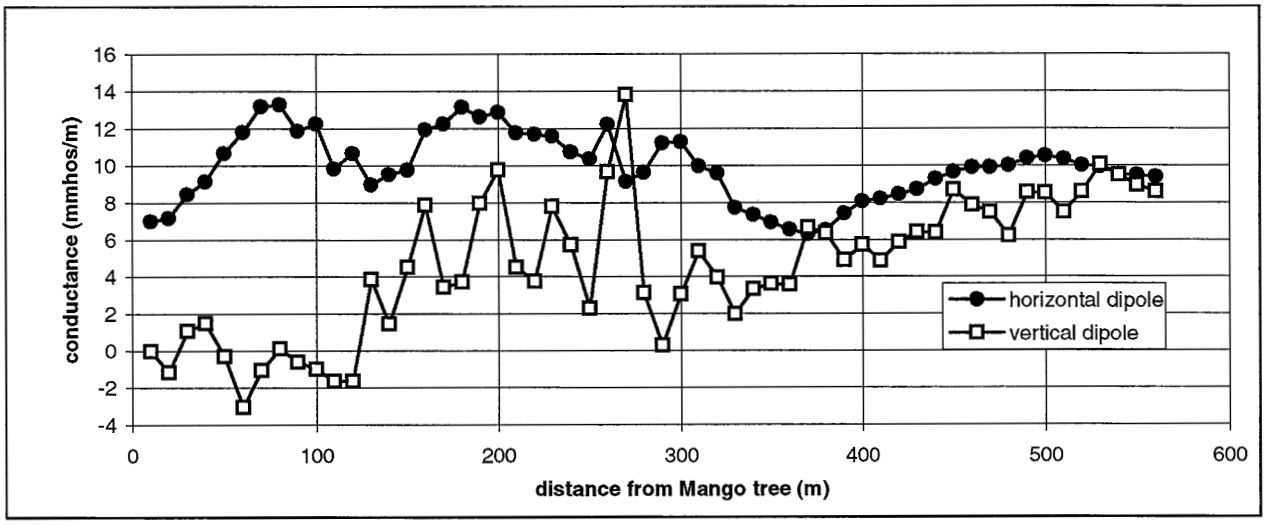
GPS start: 6 degs 48.811; 8 degs 26.930
GPS finish
Date and time: 27-28/1/98
Survey:

OY1	From mango tree at school across stream to Assemblies (EM34 - 20)
OY2	From mango across playing fields and along road to end village (EM34 - 20)
OY3	From 120 m along OY2 up to playground (EM34 - 20)
OY4	Mag as OY2
OY5	Mag as OY3
OY6	From about 40 m up OY3 passed school to playground (EM34 - 20)
OY7	From 20 m up from stream on OY6 down to 140 m X roads OY1 (EM34 - 20)

OY1:

position (m)	strike (deg)
0	246
40	233
100	250
130	256
180	242
200	230
220	210
240	236
260	250
280	263
290	268
320	257
340	266
360	262
450	248
480	243
510	230

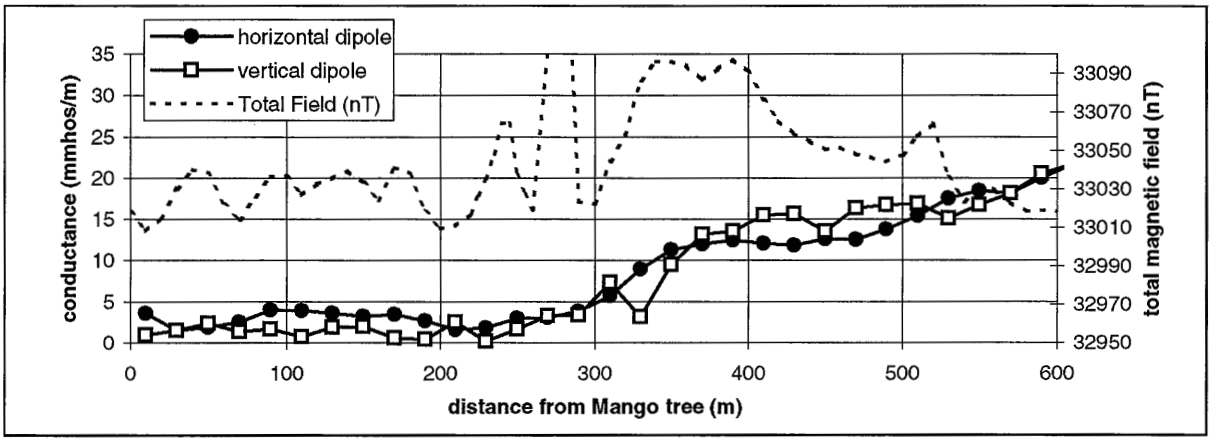
position (m)	comments
0	Mango tree - R trailing
50	path right
110	small stream - gabbro boulders
140	X roads
180	down
200	gabbro boulders
270	dried river bed - deep gully
310	small x roads
335	top of rise
470	x roads
550	Mamgo tree at Assemblies

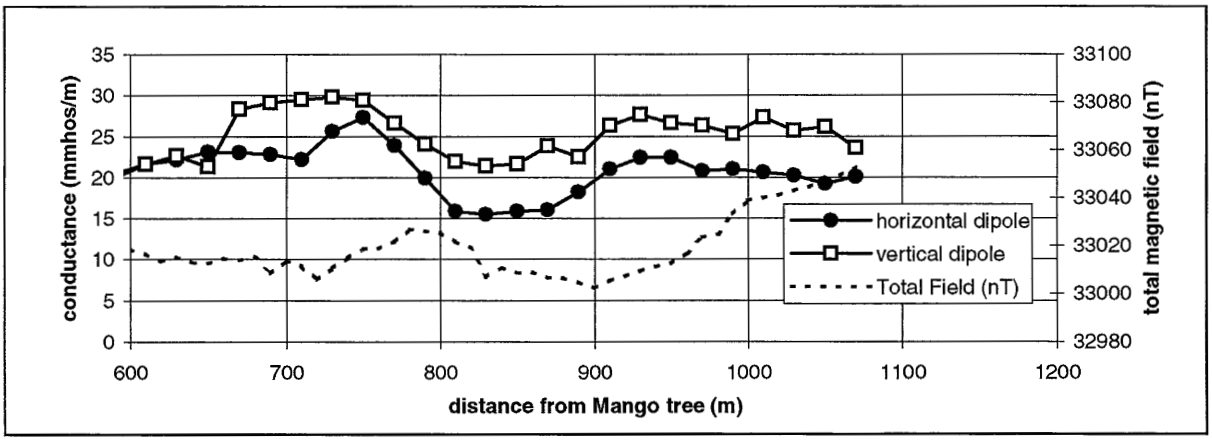


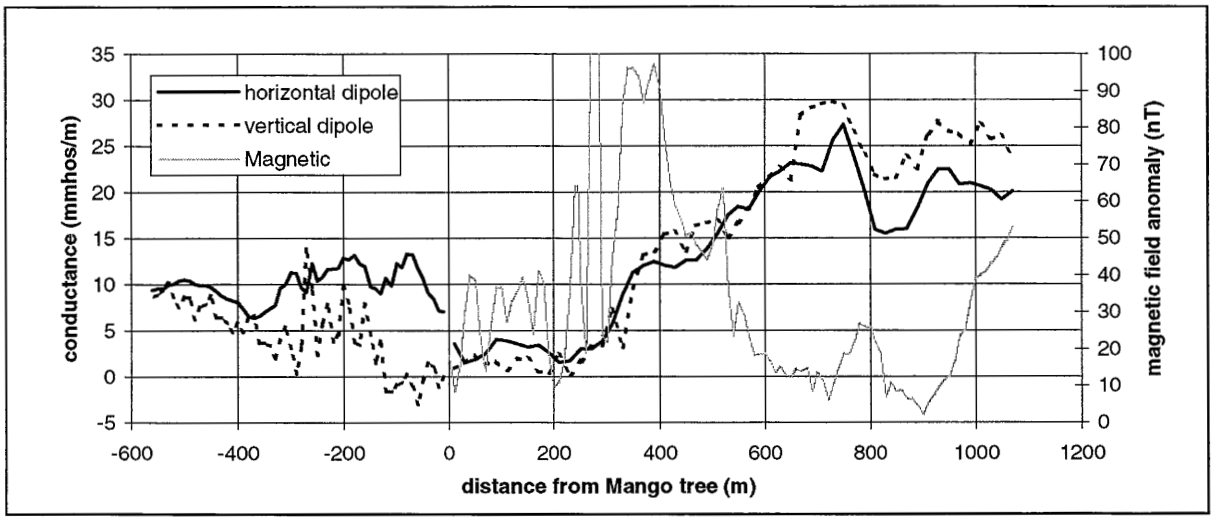
OY2 and OY4:

position (m)	strike (deg)
0	28
160	54
500	42
760	30
800	42
920	50
1020	62

position (m)	comments
0	Mango tree at start of OY1- R trailing
50	gabbro boulders
120	path at edge of field = start of OY3
160	Y junction - descending
260	boulders
280	large culvert - ascending
410	small xroads
510	oppossite JW hall
640	path left
750	boulders
900	small stream at yam farm
990	y junction



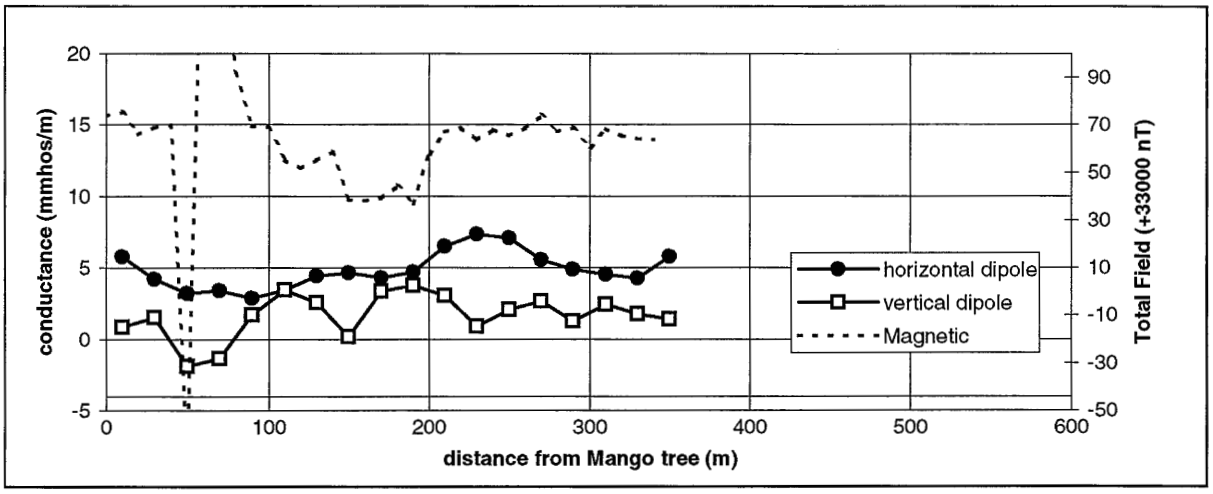




OY3 and OY5:

position (m)	strike (deg)
0	328
140	318
200	292
240	322

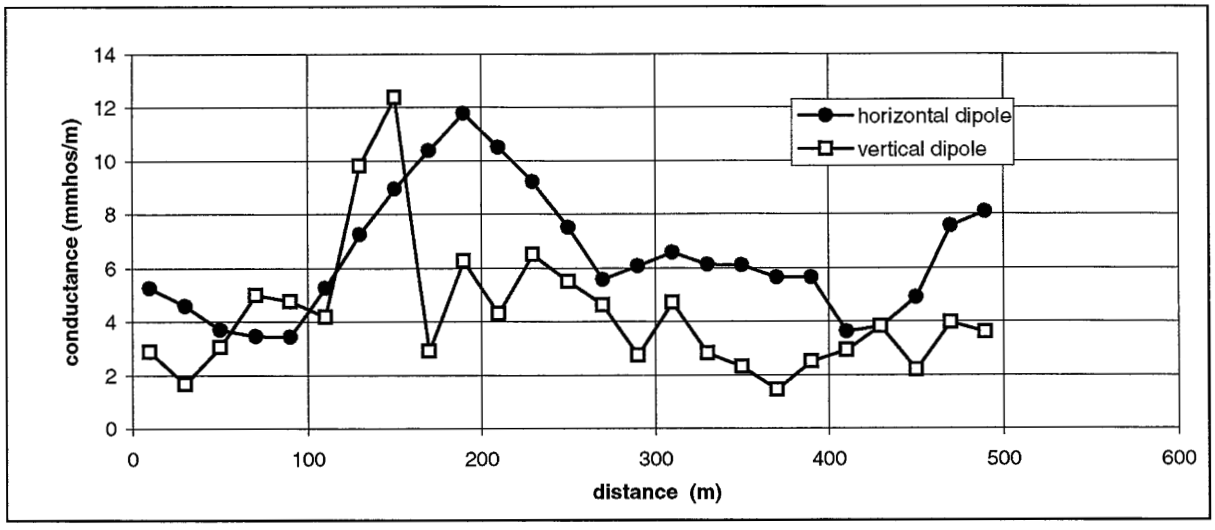
position (m)	comments
0	Start 120 m along OY2 on path
60	end of steel roof
180	small Y junction
200	T crossing
320	centre of play ground
340	large tree end playground



OY6:

position (m)	strike (deg)
0	264
100	291
140	284
200	269
220	260
240	290
260	314
280	290
380	280

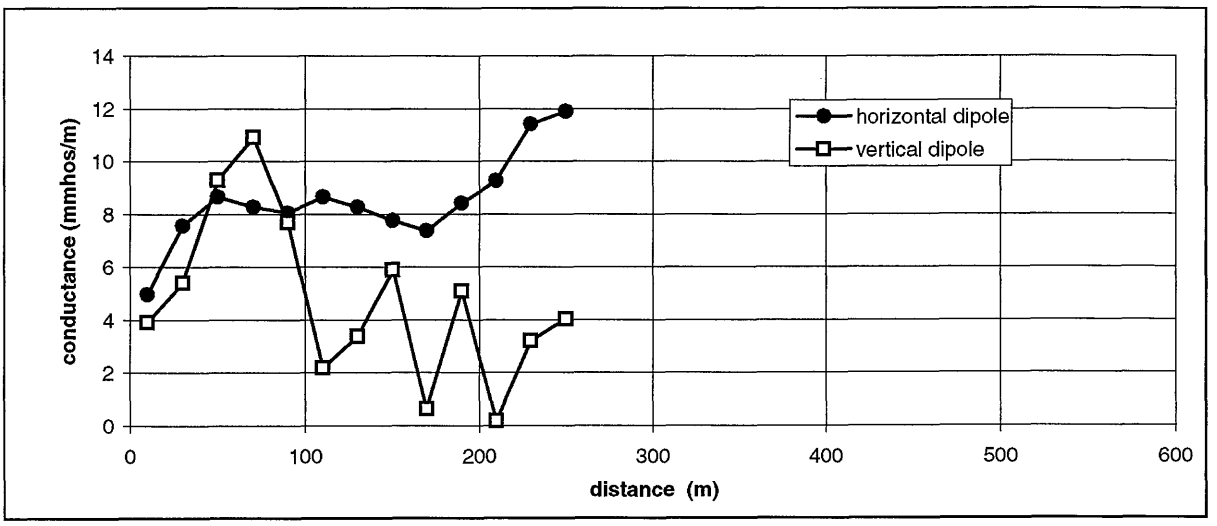
position (m)	comments
0	Start 40 m up OY3
100	R on edge school
245	small stream
320	large tree in playground
360	small path right
460	near enterance to compound
500	edge of gully



OY7:

position (m)	strike (deg)
0	191
80	152
100	134
160	144

position (m)	comments
0	Start 20 m away from stream OY6
40	rendered roundhouse
130	sleeping policeman
230	junction - crossing OY!

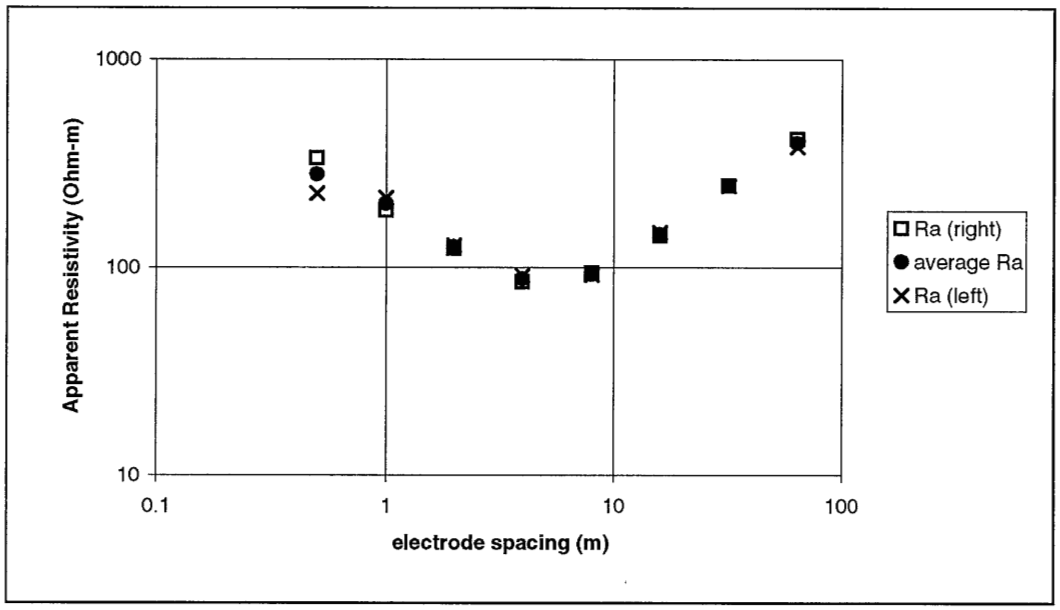


Oyinyi Iyechi

OY8

Resistivity Survey 1 6 degs 48.811; 8 degs 26.930
Located top end of playing fields, about 40 m up OY3 or 100 m along OY2
Offset Wenner Left out of village
Strike 260 degs
29/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	71.6	105.8	224.824	332.212	278.518
1	34.2	29.7	214.776	186.516	200.646
2	10.13	9.78	127.2328	122.8368	125.0348
4	3.61	3.37	90.6832	84.6544	87.6688
8	1.82	1.86	91.4368	93.4464	92.4416
16	1.453	1.4	145.9974	140.672	143.3347
32	1.224	1.22	245.975	245.1712	245.5731
64	0.939	1.024	377.4029	411.5661	394.4845



DATA SET: OY8

CLIENT: WaterAid DATE: Jan, 1998
LOCATION: Oyinyi Iyechi SOUNDING: 1
COUNTY: Oju, Nigeria AZIMUTH: 260 degs
PROJECT: Water Supply and Sanitation EQUIPMENT: BGS128
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Offset Wenner Configuration

FITTING ERROR: 2.179 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	291.6	0.808	-0.808	0.00277	235.8
2	77.47	10.53	-11.34	0.136	816.5
3	907.0				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	274.574	291.621	312.560
	2	72.053	77.471	83.057
	3	724.028	907.094	1223.274
THICK	1	0.717	0.809	0.900
	2	9.198	10.540	12.257
DEPTH	1	0.717	0.809	0.900
	2	10.052	11.349	13.019

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	278.6	271.3	2.62
2	1.00	200.7	209.5	-4.37
3	2.00	125.0	122.1	2.36
4	4.00	87.71	87.27	0.501
5	8.00	92.48	94.54	-2.22
6	16.00	143.3	142.2	0.761

* BRITISH GEOLOGICAL SURVEY *

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	245.5	244.2	0.519
8	64.00	394.5	395.8	-0.345

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	0.00	0.98		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	-0.01	0.00	0.99
	P 1	P 2	P 3	T 1	T 2

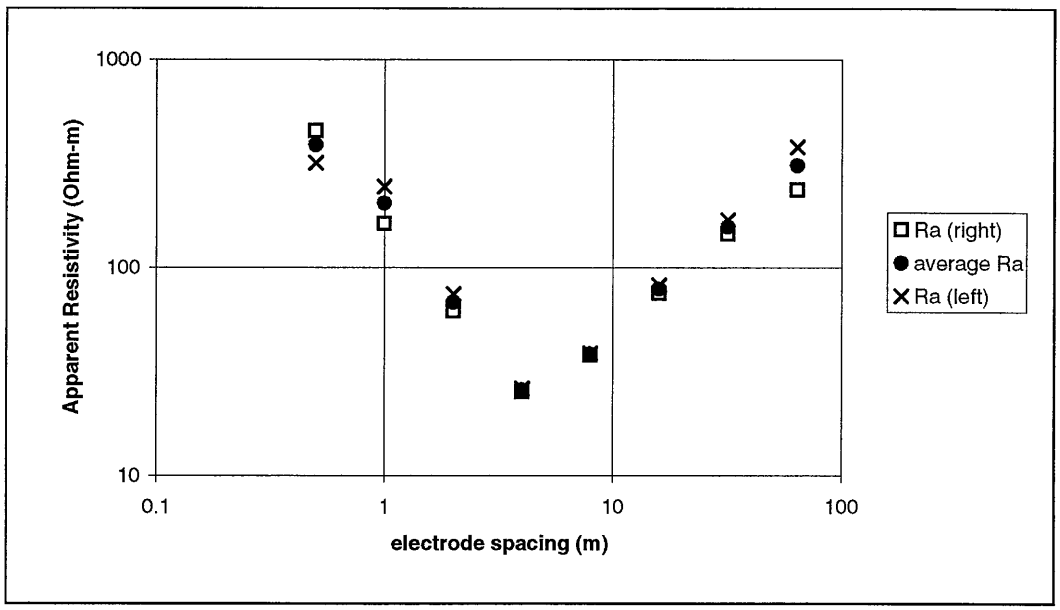
* BRITISH GEOLOGICAL SURVEY *

Oyinyi Iyechi

OY9

Resistivity Survey 2 6 degs 48.811; 8 degs 26.930
Located on junction about 120 m along OY 1 and end OY7 (230 m)
Offset Wenner Left to stream
Strike 156 degs
29/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	101.2	144.5	317.768	453.73	385.749
1	38.9	25.8	244.292	162.024	203.158
2	5.93	4.88	74.4808	61.2928	67.8868
4	1.036	1	26.02432	25.12	25.57216
8	0.7658	0.75	38.47379	37.68	38.0769
16	0.815	0.745	81.8912	74.8576	78.3744
32	0.839	0.717	168.6054	144.0883	156.3469
64	0.943	0.587	379.0106	235.927	307.4688



DATA SET: OY9

CLIENT: WaterAid DATE: Jan, 1998
LOCATION: Oyinyi Iyechi SOUNDING: 2
COUNTY: Oju, Nigeria AZIMUTH: 156
PROJECT: Water Supply and Sanitation EQUIPMENT: BGS128
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Offset Wenner Configuration

FITTING ERROR: 4.853 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	410.3	0.765	-0.765	0.00187	314.0
2	18.39	5.20	-5.96	0.282	95.67
3	13156.4				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	376.083	410.323	452.268
	2	14.376	18.396	21.893
	3	3289.121	13156.483	21062.236
THICK	1	0.716	0.765	0.818
	2	4.006	5.201	6.327
DEPTH	1	0.716	0.765	0.818
	2	4.817	5.967	7.062

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	385.9	361.3	6.36
2	1.00	203.2	224.5	-10.46
3	2.00	67.92	65.06	4.20
4	4.00	25.58	25.86	-1.08
5	8.00	38.09	39.50	-3.68
6	16.00	78.40	77.46	1.19

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	156.3	153.9	1.47
8	64.00	307.5	304.4	0.988

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.96				
P 2	-0.02	0.86			
P 3	0.00	-0.01	0.01		
T 1	0.02	0.03	0.00	0.98	
T 2	-0.03	-0.15	-0.02	0.03	0.83

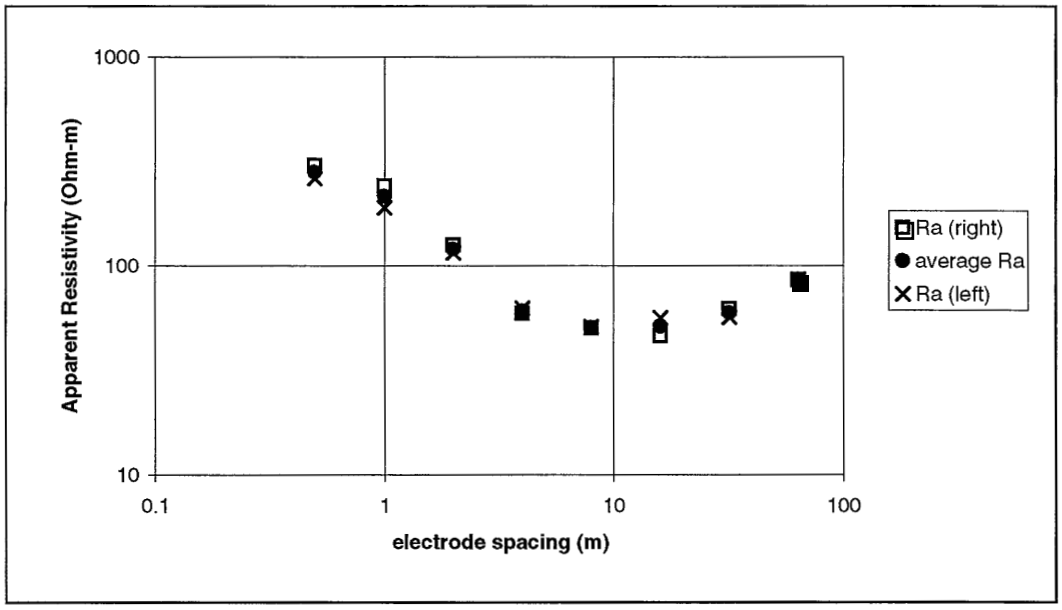
* BRITISH GEOLOGICAL SURVEY *

Oyinyi Iyechi

OY10

Resistivity Survey 3 6 degs 48.811; 8 degs 26.930
Located 600 m along OY2
Offset Wenner Left to village
Strike 39 degs
29/01/98

spacing (m)	left	right	Ra (left)	Ra (right)	average Ra
0.5	83.5	96.1	262.19	301.754	281.972
1	30.2	38.4	189.656	241.152	215.404
2	9.16	9.93	115.0496	124.7208	119.8852
4	2.47	2.33	62.0464	58.5296	60.288
8	1.007	0.993	50.59168	49.88832	50.24
16	0.558	0.457	56.06784	45.91936	50.9936
32	0.281	0.307	56.46976	61.69472	59.08224
64	0.213	0.211	85.60896	84.80512	85.20704



DATA SET: OY10

CLIENT: WaterAid DATE: Jan, 1998
LOCATION: Oyinyi Iyechi SOUNDING: 2
COUNTY: Oju, Nigeria AZIMUTH: 39 degs
PROJECT: Water Supply and Sanitation EQUIPMENT: BGS128
ELEVATION: 0.00
SOUNDING COORDINATES: X: 0.0000 Y: 0.0000

Offset Wenner Configuration

FITTING ERROR: 1.481 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	LONG. COND. (Siemens)	TRANS. RES. (Ohm-m^2)
			0.0		
1	289.6	1.00	-1.00	0.00348	291.4
2	48.95	37.88	-38.88	0.773	1854.6
3	249.4				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	271.937	289.604	311.877
	2	46.643	48.960	51.387
	3	135.050	249.438	550.207
THICK	1	0.931	1.006	1.086
	2	29.665	37.880	50.291
DEPTH	1	0.931	1.006	1.086
	2	30.709	38.887	51.286

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.500	282.1	275.5	2.33
2	1.00	215.5	222.2	-3.14
3	2.00	119.9	119.1	0.646
4	4.00	60.31	59.72	0.991
5	8.00	50.26	50.69	-0.845
6	16.00	50.99	51.04	-0.104

No.	SPACING (m)	RHO-A (ohm-m) DATA	SYNTHETIC	DIFFERENCE (percent)
7	32.00	59.08	59.06	0.0260
8	64.00	85.20	85.18	0.0128

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

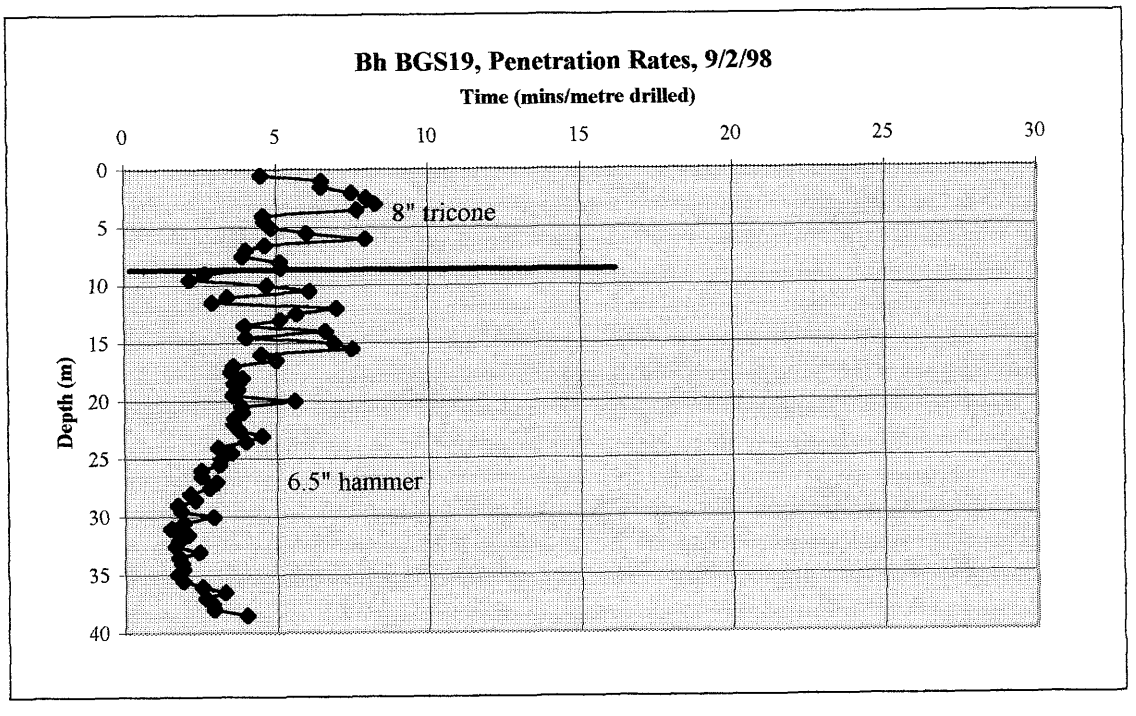
P 1	1.00				
P 2	0.00	1.00			
P 3	0.00	-0.01	0.62		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	-0.13	0.00	0.95
	P 1	P 2	P 3	T 1	T 2

* BRITISH GEOLOGICAL SURVEY *

Annex 2: Drilling and borehole construction data

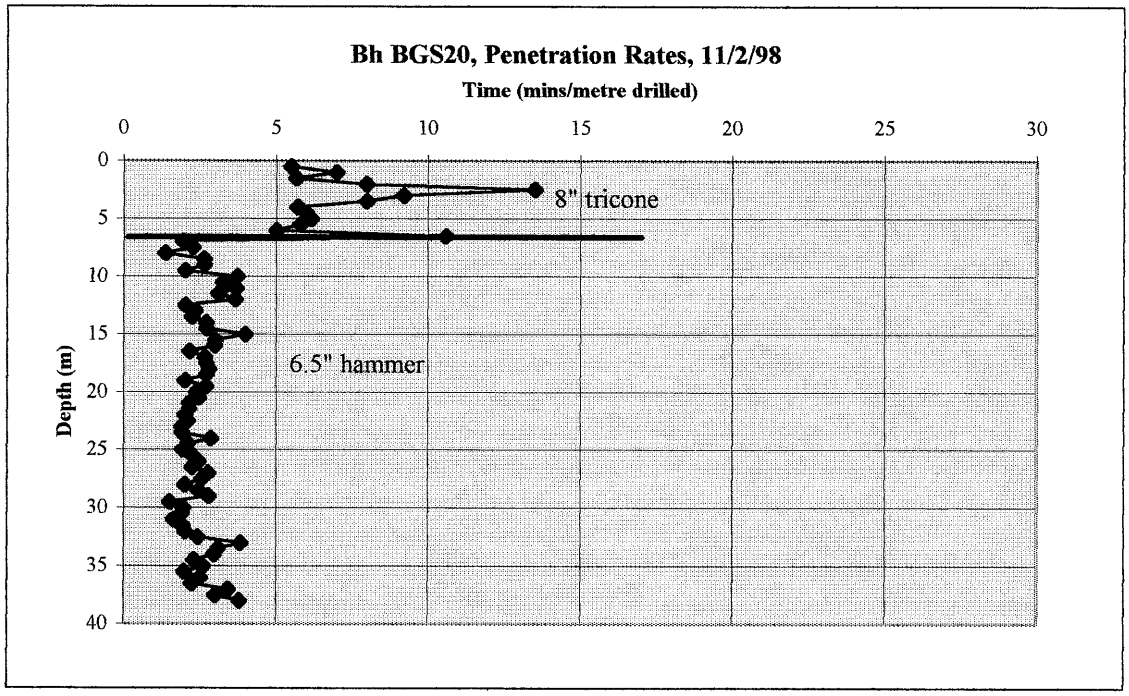
Borehole BGS19

Borehole Drilling/Construction Details	
Date drilling started	9/2/98
Date drilling completed	10/2/98
9/2/98 - Drillled with 8.5" tricone	0.0 - 8.5m
9/2/98 - Drilled with 6.5" tricone	8.5 - 27.5m
10/2/98 - Drilled with 6.5" hammer	27.5 - 38.5m
10/2//98 - Cored at 3"	38.5 - 41.5m
Depths water struck	8.5 (damp), 14.5 (flowing), 15.5 (more water), 24 (increased water)
Depth of borehole on completion	41.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	6x2.9mx125mm casing 4x5.8mx125mm screen 1x1.5mx125mm casing
Original top of casing above ground level	2.60m
Total length of casing/screen	41.5m
Amount of casing removed	2.00m
Rest water level below casing top	6.82m



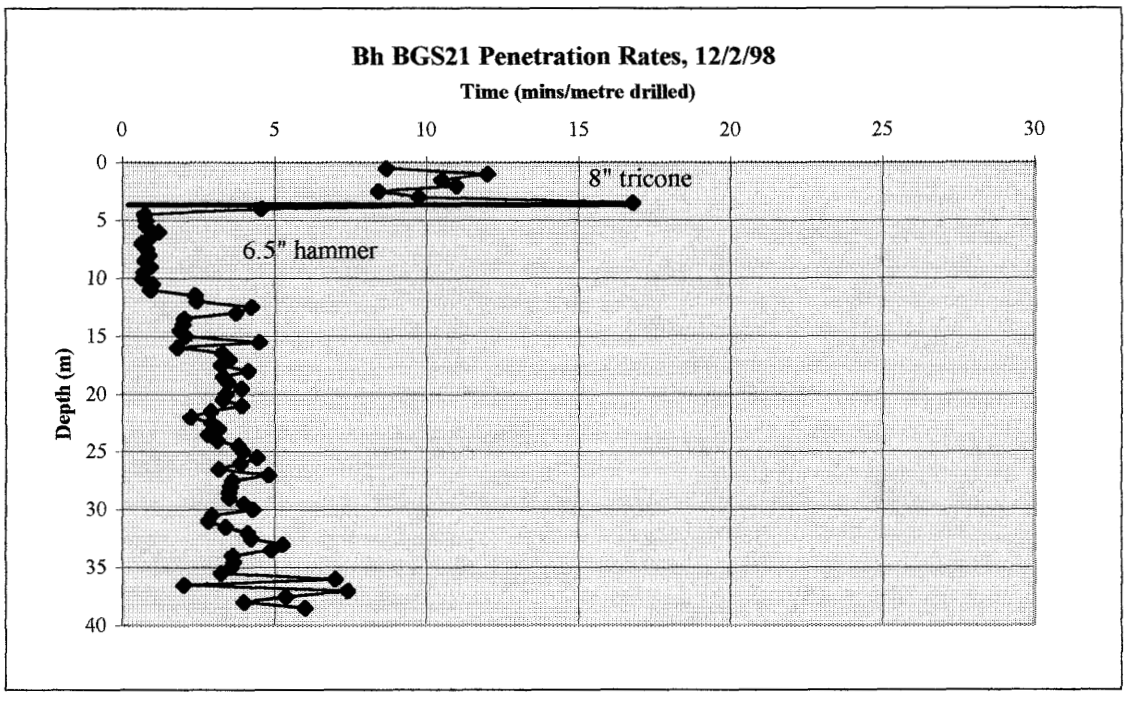
Borehole BGS20

Borehole Drilling/Construction Details	
Date drilling started	11/2/98
Date drilling completed	12/2/98
11/2/98 - Drilled with 8.5" tricone	0.0 - 6.4m
11/2/98 - Drilled with 6.5" hammer	6.4 - 38.0m
11/2//98 - Cored at 3"	38.0 - 41.0m
Depths water struck	12 (damp), 12.5 (damp), 13.0 (wet), 13.5, 14.0, 14.5, 15.0 (flowing), 15.5 increased water), 16.0 (more water), 18.5 (more water), 21.5 (flowing), 25.0 (increased flow), 36.5 (much more water)
Depth of borehole on completion	41.0mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x2.9mx125mm casing 2x5.8mx125mm casing 5x2.9mx125mm screen 2x5.8mx125mm screen
Original top of casing above ground level	1.85m
Total length of casing/screen	40.0m
Amount of casing removed	1.6m
Rest water level below casing top	2.06m



Borehole BGS21

Borehole Drilling/Construction Details	
Date drilling started	12/2/98
Date drilling completed	13/2/98
12/2/98 - Drilled with 8.5" tricone	0.0 - 3.5m
12/2/98 - Drilled with 6.5" hammer	3.5 - 38.5m
Depths water struck	4.0 (damp), 11.5 (flowing), 15.5, 19.0,
Depth of borehole on completion	38.5mbgs
Borehole diameter	$6^1/_2$"
Casing erected in hole	1x2.9mx125mm casing 2x5.8mx125mm casing 4x5.8mx125mm screen 1x2.0mx125mm casing
Original top of casing above ground level	0.50m
Total length of casing/screen	39.7m
Amount of casing removed	0.00m
Rest water level below casing top	6.54m



Annex 3: Lithological logs

Lithological log: BGS 19

Soil/ferrecrete horizon	
0.0 - 0.5	Light yellowish brown 10YR6/4 gritty soil, hard siltstone fragments
0.5 - 1.0	Yellowish brown 10YR5/8, brownish yellow 10YR6/8 and dark red 10R3/6 hard weathered quartzitic siltstones and shales
1.0 - 1.5	Brownish yellow 10YR6/8, yellowish red 5YR5/8 and red 2.5YR5/8 mottled silty clays and rock fragments
Clayey very weathered horizon	
1.5 - 2.0	Red 2.5YR5/8, brownish yellow 10YR6/8, reddish yellow 5YR6/6 and some light grey mottled silty clays and rock fragments
2.0 - 2.5	Yellow and white 10YR7/6, brownish yellow 10YR6/8, reddish yellow 7.5YR6/6-8, red 2.5YR5/8 and yellowish red 5YR5/6 mottled clays
2.5 - 3.0	Mainly yellow with reddish yellow 7.5YR6/8, yellow 10YR7/8, brownish yellow 10YR6/8, strong brown 7.5YR5/8 and white mottled clays
3.0 - 3.5	Reddish yellow 7.5YR7/6-6/8, 10YR7/4 very pale brown and brownish yellow 10YR6/6 mottled clays
3.5 - 4.0	Reddish yellow 7.5YR6/8, pale yellow 2.5Y7/4, light grey/white 2.5Y7/1, yellow 10YR7/6-8, reddish yellow 7.5YR7/6 and strong brown 7.5YR5/8 mottled clays
Very weathered shales and clay	
4.0 - 4.5	Pale yellow 2.5Y7/3 weathered shales with pale yellow 2.5Y8/3, yellow 10YR7/6, yellow brown 10YR5/8, strong brown 7.5YR5/8, brownish yellow 10YR6/8, reddish yellow 7.5YR6/8 and yellow 2.5YR7/6 mottled clays
4.5 - 5.0	Light yellowish brown 2.5Y6/4 weathered shale with reddish yellow 7.5YR7/6, brownish yellow 10YR6/6-8, olive yellow 2.5Y6/6, very pale brown 10YR7/4 and pale yellow 2.5Y7/4 mottled clays
5.0 - 5.5	Light olive brown 2.5Y5/4 and grey weathered shales with light bluish grey 8/5PB, reddish yellow 7.5YR6/6, olive yellow 2.5Y6/6, yellow 10YR7/6, very pale brown 10YR7/3 and brownish yellow 10YR6/6 mottled clays
Weathered shaley mudstones	
5.5 - 6.0	Light olive green weathered shaley mustones with brown grey, light grey and pale yellow matrix
6.0 - 6.5	Light olive brown 2.5Y5/4, olive 5Y4/3 and olive grey 5Y4/2 weathered mudstones with yellowish brown, reddish yellow 7.5YR6/8 and white mottled clays that are weathered olive yellow mudstones
6.5 - 7.0	Dark yellowish brown 10YR4/4, olive yellow 2.5Y6/6, yellowish brown 10YR5/6, brownish yellow 10YR6/6, reddish brown 5YR4/4, white and yellow 2.5Y7/6 mottled clays with limited weathering of grey mudstones
Fairly weathered shaley mudstones	
7.0 - 7.5	Light grey to grey with olive grey 5Y4/2, olive yellow 2.5Y6/6 and light olive brown 2.5Y5/6 weathered shaley mudstones with strong brown 7.5YR5/8 and yellow brown 10YR5/6 mottled clays
7.5 - 8.0	Weathered grey shaley mudstones with weathered partings of olive yellow 2.5Y6/6, yellow 2.5Y7/6, yellow 10YR7/8, pale yellow 2.5Y7/4, olive green 5Y5/2 and brownish yellow 10YR6/6.
8.0 - 8.5	Weathered olive green shaley siltstones and mudstones with some mottled clayey partings of reddish brown 5YR4/3, light olive brown 2.5Y5/4, yellow 10YR7/8, olive yellow 2.5Y6/6 and yellowish brown 10YR5/4.
Dolerite	
8.5 - 9.0	Hard dark green-black crystaline dolerite, blocky with brown weathered partings, fine grained with contact metamorphosed slatey mudstones
9.0 - 9.5	Hard black green fine to very fine grained crystalline to slatey rock, some white veining in the brown weathered partings, fine grained dolerite with black slatey mudstones
9.5 - 10.0	Hard compact fine grained dolerite with some brown weathered partings
10.0 - 10.5	Dark brown green fine grained dolerite against grey medium to coarse grained quartzite some white calcite

Interbedded hard fine to coarse grained meta-quartzite and slatey siltstones, some vein quartz	
10.5 - 11.0	Light grey fine to coarse grained metaquartzite with interbedded black silty slates, some white **calcite** veining
11.0 - 11.5	Light grey to grey medium to coarse grained metaquartzite, hard interbedded with hard black thinly laminated silty slates, some brown weathered partings
11.5 - 12.0	Light grey to grey medium to coarse grained metaquartzite, hard interbedded with hard black thinly laminated silty slates, some brown weathered partings
12.0 - 12.5	Hard grey metaquartzite medium to coarse grained some black to dark grey slatey to blocky mudstones and siltstones, some white vein **quartz**
12.5 - 13.0	Hard grey metaquartzite medium to coarse grained some black to dark grey slatey to blocky mudstones and siltstones, some white vein **quartz**
13.0 - 13.5	Interbedded grey medium to coarse metaquartzites and slatey siltstones and mudstones, some white vein **quartz** with iron **pyrite** in quartz and slates
13.5 - 14.0	Interbedded grey medium to coarse metaquartzites and slatey siltstones and mudstones, some white vein **quartz** with iron **pyrite** in quartz and slates
14.0 - 14.5	Interbedded grey medium to coarse grained sandy metaquarzite and black slatey siltstones and shaley mudstones
Interbedded hard fine to coarse grained meta-quartzite with slatey siltstones and shaley mudstones, disseminated copper and iron pyrite	
14.5 - 15.0	Interbedded grey medium to coarse grained sandy metaquarzite and black slatey siltstones and shaley mudstones with much **iron and copper pyrite** in shales
15.0 - 15.5	Interbedded grey medium to coarse grained sandy metaquarzite and black slatey siltstones and shaley mudstones with some **copper and iron pyrite**
15.5 - 16.0	Hard grey fine to medium sandy metaquartzite with black blocky to slatey siltstones and mudstones, some **pyrite**
16.0 - 16.5	Black to dark grey thickly bedded metaquartzite with disseminated **pyrite** I interbedded with hard black slatey mudstone
Blocky to slatey calcareous mudstones and limestones with iron pyrite, copper pyrite and thin quartzite	
16.5 - 17.0	Dark grey to black blocky slatey mudstones with much **copper and iron pyrite**, subordinate grey quartzite. Some muddy limestone and calcareous slates, some veined iron **pyrite**
17.0 - 17.5	Black calcareous slatey mudstone some **pyrite**
17.5 - 18.0	Black calcareous shaley to slatey mudstones and muddy limestones
18.0 - 18.5	Black calcareous shales, mudstones, muddy limestones, black noncalcareous mudstones and some grey quartzites with some iron **pyrite**
Shaley to slatey calcareous mudstones	
18.5 - 19.0	Dark grey black calcareous shaley mudstones
19.0 - 19.5	Black calcareous slatey mudstones
Slatey and shaley mudstones with hard thin quatrzitic fine grained sandstone layers	
19.5 - 20.0	Black slatey mudstones and grey hard fine grained quartzites, some disseminated iron **pyrite**
20.0 - 20.5	Black blocky to shaley and slatey calcareous mudstones, grey calcareous fine to medium grained quartzitic sandstones with carbonate cement?
20.5 - 21.0	Black dark grey slatey mudstones and siltstones, few fine to medium grained quartzitic sandstone fragments
21.0 - 21.5	Black calcareous slatey mudstones and interbedded grey fine grained metasandstones
Slatey calcareous mudstones interbedded with medium to coarse grained meta-sandstones, some pyrite	
21.5 - 22.0	Black slatey mudstones, medium to coarse grained grey metasandstones with disseminated and veined iron **pyrite**
22.0 - 22.5	Dark grey fairly calcitic slatey mudstones interbedded with grey medium to coarse grained metasandstone with disseminated iron **pyrite**
Medium to coarse graine meta-sandstones with slatey mudstones, some pyrite	
22.5 - 23.0	Light grey medium grained meta sandstone with iron **pyrite** some black slatey mudstone
23.0 - 23.5	Light grey medium to coarse grained metasandstone with veined and disseminated iron **pyrite** and some white vein **quartz**

Calcareous blocky to slatey mudstones with interbedded fine to medium grained meta-sandstones, some disseminated pyrite	
23.5 - 24.0	Black slatey blocky to shaley mudstones interbedded with grey fine to medium grained metasandstones with disseminated **pyrite**
24.0 - 24.5	Black fairly calcareous slatey blockey to shaley mudstones with grey medium to coarse quartzitic metasandstones, some disseminated iron **pyrite**
Blocky to shaley and slatey mudstones	
24.5 - 25.0	Black blocky to shaley slatey mudstones
25.0 - 25.5	Black blocky to shaley slatey mudstones
25.5 - 26.0	Black blocky to shaley slatey mudstones
26.0 - 26.5	Black shaley mudstones some iron **pyrite**
Slatey and shaley mudstones, fine to medium grained sandstones, disseminated pyrite and vein calcite, with very weathered horizon with kaolin clay	
26.5 - 27.0	Black shaley slatey mudstones, some fine grained metasandstones with much white vein **calcite** and iron **pyrite**
27.0 - 27.5	Black slatey shaley mudstones with much white vein **calcite** and some iron **pyrite**
27.5 - 28.0	Grey medium grained metasandstone and black hard slatey mudstones, much weathered brown soft partings with white kaolin
28.0 - 28.5	Grey fine to medium grained metasandstones with black slatey mudstones, much white vein **calcite**
28.5 - 29.0	Black slatey and fairly clacareous shaley mudstones and grey to dark grey fine to medium grained metasandstones, little iron **pyrite**
Slatey and shaley mudstones with disseminated pyrite and vein calcite	
29.0 - 29.5	Black slatey shaley mudstones some **pyrite**
29.5 - 30.0	Black hard slatey and shaley mudstones, some disseminated cubic iron **pyrite,** some fracturing infilled with white vien **calcite**
30.0 - 30.5	Black slatey shaley mudstones with much disseminated cubic iron **pyrite,** some white vein **calcite**
30.5 - 31.0	Black slatey silty mudstones, some nodular and cubic disseminated iron **pyrite**, much soft brown weathered material
Slatey and shaley mudstones with fine grained sandstones, dissemminated pyrite and vein calcite	
31.0 - 31.5	Black slatey and shaley mudstones, some nodular **pyrite**, somegrey fine grained sandstones with disseminated pyrite, some white vein **calcite**
31.5 - 32.0	Black slatey shaley mudstones with disseminated cubic iron **pyrite**, also grey fine grained metasandstones, some white vein **calcite**
32.0 - 32.5	Black to dark grey slatey and shaley mudstones and fine grained sandstones, some disseminated cubic iron pyrite and white vein **calcite**
Medium grained sandstone with hard slatey mudstones, some pyrite and vein calcite	
32.5 - 33.0	Some grey medium grained sandstone in black hard slatey shaley mudstones, some iron **pyrite** and white vein **calcite**
33.0 - 33.5	Some grey medium grained sandstone in black hard slatey shaley mudstones, some iron **pyrite** and white vein **calcite**
Slatey and shaley mudstones with pyrite and vein calcite	
33.5 - 34.0	Black slatey and shaley mudstones, some iron **pyrite** and white vein **calcite**
34.0 - 34.5	Black slatey and shaley mudstones, some iron **pyrite** and white vein **calcite**
34.5 - 35.0	Black slatey and shaley mudstones, some grey fine grained meta sandstones and some iron **pyrite**
Soft shaley mudstone with pyrite	
35.0 - 35.5	Black soft shaley mudstones much **pyrite**
35.5 - 36.0	Black soft shaley mudstones much **pyrite**
36.0 - 36.5	Soft black shaley musdtones, much **pyrite** and some white vein **calcite**
36.5 - 37.0	Soft black shaley mudstones some **pyrite** nodules
37.0 - 37.5	Soft black shaley mudstones much **pyrite**
Slatey mudstone with hard fine grained sandstone and iron pyrite	
37.5 - 38.0	Hard dark grey to black slatey mudstones and hard fine grained sandstones, much iron pyrite
38.0 - 38.5	Hard black slatey mudstones and hard fine grained meta-sandstones with much iron

	pyrite
38.50-38.56	Hard compact grey muddy siltstone coarsening downwards into grey/white thinly bedded fine grained sandstone
Interbedded shales, siltstones and fine to coarse grained calcareous sandstone	
38.56-38.61	Grey thin shales interbedded with thin medium grained white calcareous sandstone with much included detrital pyrite, coarsenning downwards into medium to coarse grained cross bedded white grey calcareous sandstones with pyrite in upper parts of coarse grained layers
38.61-38.62	Dark grey black carbonaceous compact mudstone with earthy to slatey cleavage
38.62	Black shaley mudstone, hard with some calcite faced slickenslides
Slatey carbonaceous mudstones, siltstones and fine to medium sandstones with pyrite	
38.63-38.69	Dark grey black carbonaceous slatey mudstones, compact and hard that grade downward into grey shaley finely bedded siltstones with some white calcite along the joints
38.69-38.80	Grey compact to shaley hard siltstone with thin white grey sandstone partings (at the base of each fining upward cycle) with pyrite in the sandstone layer at 38.75-38.76 m.
38.80-38.94	Hard grey compact siltstones with thin bands of white sandstones, pyrite associated with thin sandstones betwee 38.85-38.86, some calcite filled fractured between 38.92-38.94 m
38.94-39.11	Thinly cross-bedded grey shaley fine sandstones with pyritic upper parts grading downwards into medium grained cross-bedded sandstones, white and grey to 38.98 m
38.98-39.00	Dark grey black carbonaceous compact hard mudstones grading down into grey siltstones, hard and compact from 39.00-39.11 with thin white sandstones associated with thin pyrite bands at 39.045 and 39.06 m. Prominant sub-vertical calcite filled cracks.
39.11-39.12	Thinly bedded white sandstone band
39.12-39.21	Grey to dark grey thinly bedded hard compact shaley siltstones
39.21	Thinly bedded white and grey fine sandstone band, some yellow iron pyrites
39.21 - 39.225	Dark grey mudstone to grey siltstone, hard and compact
39.225 - 39.245	White medium grained and grey fine grained sandstone bands, cross bedded some load casts
39.245 - 39.30	Grey thinly bedded compact siltstoneswith very thin white sandstone bands at 39.26, 39.275 and 39.295 m
Interbedded siltstones and hard fine grained sandstones with pyrite and calcite	
39.30 - 39.31	thin white shaley sandstones with pyrite39.31 - 39.45 m - fining upwards cycles of muddy siltstones with basal thin white sandstones bands at 39.32, 39.38, 39.41 and 39.44 m Prominent white veined subvertical fractures infilled with white calcite from 39.11 to 39.45 m
39.45 - 39.58	Grey hard compact siltstones with thin sandstones at 39.47 and 39.53 (last with much iron pyrite)
39.58 - 39.90	Nmerous fining upwards cycles of hard compact grey siltstones with thin basal white sandstones at 39.65 (with iron pyrite), 39.74, 39.77 (with iron pyrite) 39.78, 39.80, 39.83 (with iron pyrite), 39.84, 39.85, 39.87 and 39.89
Interbedded mudstones, siltstones and compact fine grained sandstones with pyrite	
39.90 - 40.13	Dark grey mudstones above light grey siltstone with basal thin white calcareous sandstone fining upwards cycles, sandstone bands at: 39.95, 39.965 (with thick iron pyrite), 40.01 (some iron pyrite), 40.035, 40.055, 40.08 and 40.12 m
40.13 - 40.44	Thick iron pyrite band at 40.13 - 40.135 m. Fining upwards cycles of dark grey mudstones above light grey siltstone with basal thin white calcareous sandstone, sandstone bands at: 40.155, 40.19, 40.215, 40.22, 40.31, 40.345, 40.355 (with thick iron pyrite band), 40.36 (some iron pyrite), 40.40, 40.41 and 40.425 m
40.45 - 40.56	Dark grey hard and compact mudstones
40.46 - 40.47	grey well bedded siltstones
40.47 - 40.53	thin white medium grained sandstones alternating with fine grained grey sandstones
40.53 - 40.545	with thick irone pyrite layer above black mudstones
40.545 - 40.55	above light grey siltstones
40.57 - 40.75	Light grey hard and compact siltstones to 40.675 m. Thinly bedded white medium grained sandstone with prominent load cast structures 40.675 - 40.685 m. Thinly

	bedded grey and sometimes white fine grained sandstones to 40.71 m. Dark grey mudstones and grey siltstones above medium grained white and fine grained grey sandstones to 40.745 m , with load cast structures in white sandstones at 40.73 m. Pyrite and calcite along bedding plane at 40.75
40.75 - 40.90	Grey siltstones with thin sandstones above dark grey mudstones at 40.825 - 40.83 m
40.90 - 41.35	Grey hard compact muddy siltstones with thin white sandstone bands at 40.91 - 40.93 m. Some pyrite at 41.13 m, prominent pyrite band at 41.35 m with cubic crystal form, some clacite also in a subvertical fracture

Lithological Log: BGS20

Soil/ferrecrete horizon	
0.0 - 0.5	Reddish yellow 7.5YR6/8 and yellowish red 5YR5/6 mottled clayey soil and weathered shale fragments
0.5 - 1.0	Reddish yellow 7.5YR7/8 and yellowish red 5YR5/6 mottled clayey soil
1.0 - 1.5	Mottled yellow 2.5Y7/8 and red 2.5YR4/8 weathered shaley mudstones, some clay development
1.5 - 2.0	Mottled red 2.5YR4/8, yellow 10YR7/8 and brownish yellow 10YR6/8 clayey weathered hard shaley mudstones
2.0 - 2.5	Mottled red 2.5YR4/8, brownish yellow 10YR6/8 and reddish yellow 7.5YR6/8 clayey weathered shales
Clayey very weathered horizon	
2.5 - 3.0	Light bluish grey 8/5B and 10YR6/8 brownish yellow mottled silty clay
3.0 - 3.5	Mottled yellowish brown 10YR5/8 and brownish yellow 10YR6/8 silty clay with some light bluish grey 8/5B clay
3.5 - 4.0	Mottled yellowish brown 10YR5/8 and yellow 2.5YR7/8 clays with pale yellow 5Y8/3 to light grey 5Y7/1 and white partings
4.0 - 4.5	Olive yellow 2.5Y6/6 silty clay with light greenish grey clay 8/10GY to 7/5GY and yellowish red 5YR5/8 to strong brown 7.5YR5/8 clayey partings
4.5 - 5.0	Yellow 2.5Y7/6 clay with mottles of yellow 2.5Y8/6, white 2.5Y8/1, strong brown 7.5YR5/8 and light greenish grey clays
5.0 - 5.5	Pale yellow 2.5Y8/4 and olive yellow 2.5Y6/6 clays with mottles of brownish yellow 10YR6/8 and dark grey 10YR4/1 clays
Weathered blocky mudstones with clay	
5.5 - 6.0	Weathered light olive brown 2.5Y5/6 clay and dark grey hard blocky mudstones
6.0 - 6.5	Yellow 2.5Y7/8 weathered clay with red 2.5YR5/8 mottles, with dark grey unweathered hard shaley mudstones
Muddy limestone fairly weathered	
6.5 - 7.0	Hard dark grey fine grained muddy limestone with yellow 2.5Y7/8 clay
7.0 - 7.5	Hard dark grey fine grained muddy limestone, angular fracture, orange yellow weathered partings
7.5 - 8.0	Hard dark grey fine grained muddy limestone, angular fracture, orange yellow weathered partings
Muddy limestone	
8.0 - 8.5	Hard dark grey fine grained muddy limestone, angular fracture
8.5 - 9.0	Grey to dark grey shaley muddy limestone, fairly hard
9.0 - 9.5	Grey to dark grey fine grained limestone interbedded with hard dark grey non calcareous shales
9.5 - 10.0	Dark grey muddy limestones
10.0 - 10.5	Dark grey muddy limestones with light grey partings
10.5 - 11.0	Dark grey fine grained muddy limestone with light grey partings
Muddy limestone with shales	
11.0 - 11.5	Dark grey muddy limestones with interbedded dark grey to black non-calcareous shales
11.5 - 12.0	Dark grey blocky limestones interbedded with noncalcareousblack to dark grey siltstones and shaley mudstones, some iron pyrite in shales
12.0 - 12.5	Dark grey muddy limestones, some white **clacite** veining, some iron **pyrite** in shales
12.5 - 13.0	Dark grey muddy limestones, some thinly bedded black to dark grey noncalcareous shales
Muddy limestone with vein calcite	
13.0 - 13.5	Dark grey muddy limestone with much white vein **calcite**
13.5 - 14.0	Dark grey muddy limestone with much white vein **calcite**
14.0 - 14.5	Dark grey muddy limestone with white vein **calcite**
14.5 - 15.0	Dark grey muddy limestone with yellow very weathered ash?? partings, some white vein **calcite**

Muddy limestone	
15.0 - 15.5	Dark grey muddy limestone
15.5 - 16.0	Dark grey muddy limestone
16.0 - 16.5	Dark grey muddy limestone with hard slatey dark grey noncalcareous **pyritic** mudstones, some yellow weathered partings
Non-calcareous shales with muddy limestones, some pyrite and weathered ash	
16.5 - 17.0	Dark grey muddy limestones interbedded noncalcareous black to dark grey slatey shales, some yellow weathered **ash**?? partings
17.0 - 17.5	Dark grey slatey shales, noncalcareous with grey muddy limestones, some weathered yellow brown and light grey **ash**y?? layers
17.5 - 18.0	Dark grey blocky **pyritic** mudstones interbedded with dark grey very muddy limestones
18.0 - 18.5	Dark grey muddy limestones, calcareous mudstones and noncalcareous shales
18.5 - 19.0	Dark grey shaley noncalcareous mudstones, little dark grey muddy limestone, some **pyrite** in shales
Hard shaley calcareous mudstones and noncalcareous shales with pyrite	
19.0 - 19.5	Dark grey hard calcareous mudstones, some dark grey noncalcareous shales with **pyrite**
19.5 - 20.0	Hard dark grey shaley calcareous mudstones
20.0 - 20.5	Hard dark grey shaley calcareous mudstones some orange yellow weathered partings
20.5 - 21.0	Hard calcareous dark grey shaley mudstones, some **pyrite**, some dark grey noncalcareous shales
Noncalcareous shaley and slatey mudstone with pyrite	
21.0 - 21.5	Dark grey to black shaley noncalcareous mudstones with interbedded dark grey muddy limestone
21.5 - 22.0	Dark grey to black shaley mudstone, some iron **pyrite**
22.0 - 22.5	Dark grey to black thin laminated shaley to slatey mudstone, some iron **pyrite**
22.5 - 23.0	Dark grey to black thin laminated shaley to slatey mudstone
23.0 - 23.5	Dark grey to black thin laminated shaley to slatey mudstone with iron **pyrtie** and some light brown soft weathered biscuity and clayey sandstone or **ash**
23.5 - 24.0	Dark grey black thinly bedded shaley to slatey mudstones, some iron **pyrite**
Shaley and slatey calcareous mudstones with muddy limestone and pyrite	
24.0 - 24.5	Dark grey to black shaley to slatey thinly bedded mudstone with iron **pyrite**, calcareous in parts. Odd blocky fragment of grey muddy limestone
24.5 - 25.0	Dark grey to black thinly bedded shaley to slatey mudstone, some fairly calcareous layers, some iron pyrite. Odd fragments of orange brown weathered biscuit (**ash**) and dark grey limestone
Shaley and slatey mudstone with pyrite	
25.0 - 25.5	Dark grey to black slatey to shaley mainly noncalcareous mudstones
25.5 - 26.0	Dark grey to black slatey to shaley mudstones
26.0 - 26.5	Dark grey to black slatey to shaley mudstones, calcareous in parts with odd fragment of black muddy limestone
26.5 - 27.0	Dark grey to black slatey to shaley mudstones, calcareous in parts with odd fragments of black muddy limestone, and yellow orange weathered **ash**
27.0 - 27.5	Dark grey to black slatey to shaley mudstones
27.5 - 28.0	Dark grey to black slatey to shaley mudstones
28.0 - 28.5	Dark grey to black slatey to shaley mudstones, with copper and iron **pyrite**
28.5 - 29.0	Dark grey to black shaley mudstones, with some iron **pyrite** and odd large fragments of dark grey muddy limestones
29.0 - 29.5	Dark grey to black shaley mudstones, some iron **pyrite**
29.5 - 30.0	Dark grey to black slatey to shaley mudstones, some iron **pyrite**
Slatey and shaley noncalcareous and calcareous mudstones, some weathered ash	
30.0 - 30.5	Dark grey to black noncalcareous slatey to shaley thinly laminated mudstones and fairly calcareous mudstones and muddy limestones
30.5 - 31.0	Dark grey to black slatey to shaley mudstones with numerous fragments of yellow and orange weathered **ash**
31.0 - 31.5	Dark grey shaley mudstones, some yellow orange weathered **ash** fragments

Shaley calcareous mudstones, some muddy limestone, some weathered ash, pyrite and calcite	
31.5 - 32.0	Dark grey fairly calcareous shaley mudstones, odd fragments of grey muddy limestones and greyish orange weathered **ash**
32.0 - 32.5	Dark grey shaley fairly calcareous mudstones with some white vein **calcite**
32.5 - 33.0	Dark grey to black shaley fairly calcareous mudstone, odd fragment of white vein **calcite** and nodule of iron **pyrite**
33.0 - 33.5	Dark grey to black shaley to blocky calcareous mudstones, some iron **pyrite** and fragments of orange weathered **ash**
33.5 - 34.0	Dark grey fairly calcareous shaley mudstones, some grey calcareous mudstones, numerous fragments of orange and light grey weathered **ash**
34.0 - 34.5	Dark grey to black faily calcareous shaley mudstones, some iron **pyrite** and fragments of orange and yellow weathered **ash**
Shaley calcareous mudstones and muddy limestone, much pyrite and weathered ash	
34.5 - 35.0	Dark grey black shaley mudstones with some light grey muddy limestones, much iron **pyrite**, some fragments of weathered orange and light grey **ash**
35.0 - 35.5	Dark grey to black fairly calcareous shaley mudstones with fragments of grey muddy limestone and weathered yellow grey **ash**, some iron **pyrite**
Shaley mudstone and muddy limestone with weathered ash and pyrite	
35.5 - 36.0	Dark grey black shaley mudstones, some iron **pyrite**
36.0 - 36.5	Dark grey to black blocky to shaley mudstone with large fragments of grey muddy limestone and numerous fragments of yellow and light grey medium grained weathered **ash**
36.5 - 37.0	Dark grey to black noncalcareous shaley mudstones with odd very large fragments of grey muddy limestone and numerous large fragments of orange, yellow and light grey soft **ash**, some white vein **quartz**
37.0 - 37.5	Dark grey to black shaley mudstones, some iron **pyrite**, numerous large fragments of weathered soft yellow and light grey **ash**
37.5 - 38.0	Dark grey to black shaley mudstone with numerous large fragments of weathered soft yellow and light grey fine to medium grained **ash** deposits, also some fragments of grey muddy limestone
Siltstone, fine grained sandstone with pyrite	
38.00	downwards - Dark grey compact finely bedded, cross-bedded siltstone to fine grained sandstone with disseminated iron pyrite. Iron pyrite deposited along bedding planes and joint/fracture planes as at:
38.18	occurring with thin white **calcite** band
38.28	pyrite along horizontal joint plane
38.44	pyrite along horizontal joint plane
38.44-38.47	pyrite along 45° dipping cleavage plane
38.55	pyrite along horizontal joint plane
38.68-38.72	fault zone with **iron pyrite, chalcopyrite** and other sulphides?? as well as **calcite**
Silty mudstone and sandstone with pyrite	
38.72	downwards - Dark grey very compact finely bedded silty mudstone with 45° dipping slatey cleavage, finely disseminated iron **pyrite**
38.82	5mm wide **calcite** band with iron **pyrite** at outer rims
39.06	Thin horizontal pyrite band
39.28	5mm thick band of vesicular **pyrite**
39.28-39.32	Thinly bedded hard dark grey and white cross-bedded sandstone
39.30-39.35	Nodule of heavy sulphides surrounded by rim of iron **pyrite** with cubic form
Hard siltstone with pyrite	
39.35	downwards - Hard compact siliceous grey finely bedded siltstone with horizontal bedding and cleavage, little finely disseminated iron **pyrite**
39.54	**Pyrite** on horizontal bedding plane
39.59	**Pyrite** along horizontal bedding plane
Hard slatey mudstone with pyrite	
39.59	downwards -

	Finely bedded very compact hard dark grey slatey mudstones with finely disseminated iron **pyrite** along bedding planes
39.63	Thin crush zone with **pyrite** rim and some **calcite**
39.70	**Pyrite** along horizontal bedding plane
39.84-39.86	**clacite** filled horizontal crack with adjacent **pyrite** filled crack
39.91	45° cleavage joint with some iron **pyrite**
40.14	END OF CORE

Lithological Log: BGS21

Soil/ferrecrete horizon	
0.0 - 0.5	Strong brown 7.5YR5/6 clayey soil with reddish yellow 7.5YR6/8 streaks and weathered shaley fragments
0.5 - 1.0	Reddish yellow 5YR6/6 and reddish yellow 7.5YR6/6 sandy and clayey soil
Clayey very weathered horizon	
1.0 - 1.5	Reddish yellow 5YR6/6 and reddish yellow 7.5YR6/6 sandy and clayey soil
1.5 - 2.0	Yellow 10YR7/8, red 2.5YR5/8 and pale yellow 2.5Y8/4 mottled silty clays, very weathered hard shales
Very weathered clayey shales	
2.0 - 2.5	Mottled yellow 10YR7/8, red 2.5Y5/8 and pale yellow 2.5Y8/4 clays with hard platey fragments of grey shale with some black manganese oxide partings
2.5 - 3.0	Mottled brownish yellow 10YR6/8, reddish yellow 7.5YR6/8, red 2.5YR5/8 and light grey 2.5Y7/1 clays with grey shale fragments
3.0 - 3.5	Mottled yellowish brown 10YR5/6-5/8, olive yellow 2.5Y6/6 and brownish yellow 10YR6/8 clayey weathered shales, some fragments of hard weathered grey shale
3.5 - 4.0	Mottled light bluish grey 8/10B to bluish grey 5/10B clays and yellowish brown 10YR5/8 sandy clay with hard weathered shale fragments
Fairly weathered carbonaceous shaley mudstone	
4.0 - 4.5	Black blocky carbonaceous shales with brownish yellow 10YR5/8 and bluish grey weathered horizons
4.5 - 5.0	Black carbonaceous shaley mudstones with brownish yellow 10YR5/8 and reddish yellow weathered horizons
5.0 - 5.5	Black carbonaceous shaley mudstones with weathered dark greyish brown 2.5Y4/2 and clayey yellow 2.5Y7/6 weathered partings
Weathered carbonaceous shaley mudstone, some clay	
5.5 - 6.0	Light yellow brown 2.5Y6/4 sandy matrix with fragments of black carbonaceous shaley mudstones with very weathered horizons of brownish yellow 10YR6/8 and light blue grey sandy clays
6.0 - 6.5	Fine grained matrix of pale olive 5Y6/3 weathered shale fragments mixed with mottled grey 5Y6/1, strong brown 7.5YR5/6, brownish yellow 10YR6/8 and light bluish grey 8/10B clays
6.5 - 7.0	Weathered black carbonaceous shaley mudstone with fine grained light olive matrix, with orange brown and light bluish grey weathered partings
7.0 - 7.5	Weathered grey shale, olive matrix with yellow, orange and light grey weathered partings
7.5 - 8.0	Weathered olive sandy matrix of hard grey shales and orange grey weathered partings
Fairly weathered carbonaceous shaley mudstone	
8.0 - 8.5	Black carbonaceous shaley mudstone fragments with olive matrix of weathered grey shales and orange and grey clayey partings
8.5 - 9.0	Black carbonaceous shaley mudstone fragments with olive matrix of weathered grey shales and orange and grey clayey partings
9.0 - 9.5	Dark olive grey matrix of mainly black carbonaceous mudstones with few olive weathered horizons
9.5 - 10.0	Olive grey matrix of black carbonaceous mudstone fragments and increased olive weathered partings
10.0 - 10.5	Weathered olive matrix of black carbonaceous fragments and orange, grey and olive weathered partings
Carbonaceous mudstone with interbedded medium to coarse grained muddy sandstone	
10.5 - 11.0	Black carbonaceous mudstones with some dark olive grey weathered horizons
11.0 - 11.5	Black carbonaceous mudstones interbedded with medium to coarse grained grey white muddy sandstones, some calcitic cement
Hard coarse grained meta-sandstone with slatey mudstone	
11.5 - 12.0	Interbedded hard slatey black mudstones weathered orange brown in parts and hard coarse grained metaquartzites carbonaceous partins and some calcareous scemt, some

	white vein **calcite**
12.0 - 12.5	Hard competent dark grey coarse grained meta-sandstone with brown grey weathered partings, some white vein calcite and calcareous cement, intergrowths of quartz grains and carbon - black fragments.
12.5 - 13.0	Dark grey and speckled white coarse grained metamorphosed carbonaceous sandstone with calcitecement, with interbedded dark grey slatey mudstone
13.0 - 13.5	Dark grey coarse grained meta-sandstone above hard black carbonaceous slatey mudstones
Hard slatey carbonaceous mudstone	
13.5 - 14.0	Black hard slatey meta-mudstone, calcareous in parts, some white **calcite** veining
14.0 - 14.5	Hard black carbonaceousslatey mudstone, some iron **pyrite** veining
14.5 - 15.0	Hard black carbonaceous slatey meta-mudstone, some coarser silty bands
15.0 - 15.5	Hard black carbonaceous metamorphosed slatey mudstones above grey fine to medium to coarse grained quartzitic metasandstones with calcareous? cement
Hard metamorphosed carbonaceous slatey mudstone and siltstone, some medium grained meta-sandstone	
15.5 - 16.0	Hard black carbonaceous metamorphosed slatey siltstone
16.0 - 16.5	Hard black to dark grey medium to fine grained carbonaceous metasandstone with interbedded black hard slatey meta-mudstones
16.5 - 17.0	Interbedded hard black slatey mudstones and black to dark grey medium grained carbonaceous quartzitic metasandstone with calcareous cement, some orange brown weathered partings
17.0 - 17.5	Black and dark grey hard carbonaceous slatey mudstone and siltstone, metamorphosed with some white vein **calcite**
17.5 - 18.0	Black carbonaceous hard slatey mudstone, with dark grey to grey medium grained quartzitic sandstone, much white vein **calcite** and veined iron **pyrite**
Hard metamorphosed slatey mudstone and siltstone, some chalcopyrite.	
18.0 - 18.5	Black medium grained hard crystalline rock (pyroxene hornfels?), possible contact metamorphic rock with biotite and disseminated **chalcopyrite**
18.5 - 19.0	Hard black recrystallised metamorphosed slatey mudstone, some orange brown weathered partings
19.0 - 19.5	Hard black slatey mudstones and siltstones, carbonaceous with some light grey and orange weathered partings
19.5 - 20.0	Hard black slatey mudstones and grey medium grained metasandstones with disseminated **iron pyrite and chalcopyrite**
Slatey metamorphosed carbonaceous mudstones interbedded with schistose medium grained meta-sandstone, much disseminated pyrite	
20.0 - 20.5	Hard black metamorphosed mudstone with slatey cleavage interbedded with medium grained quartzitic meta-sandstone, schistic fabric, with disseminated **pyrite**, many white vein **calcite** fragments
20.5 - 21.0	Hard black metamorphosed mudstone with slatey cleavage interbedded with medium grained quartzitic meta-sandstone, schistic fabric, with disseminated **pyrite**, many white vein **calcite** fragments
21.0 - 21.5	Black metamorphosed slatey carbonaceous mudstone to siltstone with grey metasandstone, medium grained with schistose fabric and disseminated **pyrite**
Metamorposed slatey mudstone and siltstone	
21.5 - 22.0	Dark grey black slatey metamorphosed mudstones, some **pyrite**
22.0 - 22.5	Dark grey to black slatey metamorphosed carbonaceous mudstones and siltstones
Slatey metamorphosed carbonaceous mudstones interbedded with schistose medium grained meta-sandstone, much disseminated pyrite	
22.5 - 23.0	Black and dark grey slatey metamorphosed carbonaceous mudstones interbedded with medium grained blocky metasandstone with schistose fabric, some disseminated **chalcopyrite and iron pyrite**
23.0 - 23.5	Black phylitic and slatey metamorphosed carbonaceous mudstones interbedded with medium grained metasandstones with black strained schistose fabric
23.5 - 24.0	Black phylitic slatey mudstones with subordinate medium grained grey metasandstones with thin veins of **pyrite** and white **calcite**
24.0 - 24.5	Interbedded black phylitic to slatey mudstones and medium grained schistose black to

	grey metasandstone with disseminated **pyrite**
24.5 - 25.0	Interbedded black phylitic to slatey mudstones and medium grained schistose black to grey metasandstone with disseminated **pyrite**
Medium to coarse grained metaquartite with phylitic and slatey mudstones, some disseminated pyrite	
25.0 - 25.5	Grey medium to coarse grained metaquartzitic sandstone with some disseminated **pyrite**, subordinate black phylitic and slatey mudstones
25.5 - 26.0	Grey medium to coarse grained metaquartzitic sandstone with some disseminated **pyrite**, subordinate black phylitic and slatey mudstones, increased orange brown weathered fragments
26.0 - 26.5	Grey medium to coarse grained metaquartzitic sandstone with black to dark grey phylitic slatey mudstones, some chalcopyrite with vein **baryte** and weathered orange fractures
26.5 - 27.0	Grey medium to coarse metasandstone with some hard phylitic black slatey mudstones and siltstones
27.0 - 27.5	Dark grey medium to coarse metasandstone with disseminated **pyrite** and subordinate black phylitic mudstones
27.5 - 28.0	Grey medium to coarse grained meta sandstone with subordinate black phylitic and slatey mudstones with some white **calcite** veining
Slatey carbonaceous mudstone interbedded with fine to coarse grained meta-quartzite	
28.0 - 28.5	Dark grey slatey carbonaceous mudstones interbedded with grey and speckled white medium to coarse grained metasandstone
28.5 - 29.0	Dark grey slatey and phylitic mudstones interbedded with grey and speckled white fine to medium grained metasandstones, some **chalcopyrite** in the latter
29.0 - 29.5	Dark grey slatey mudstones, some weathered brown, interbedded with dark grey fine to medium quartzitic metasandstones
29.5 - 30.0	Dark grey to black fine grained slatey mudstone and grey to dark grey medium to coarse grained metasandstone with white grains and black cement, strained hard texture with some disseminated **pyrite**
30.0 - 30.5	Black thinly laminated slatey mudstones, some slatey metasandstone bands
Hard metamorphosed interbedded fine to medium sandstone, siltstone and slate, some chalcopyrite	
30.5 - 31.0	Black finely laminated slatey mudstones, some meta siltstones and fine grained meta sandstones
31.0 - 31.5	Black hard fine grained metamophosed carbonaceous shales, siltstones and sandstones
31.5 - 32.0	Black fine to medium grained crystaline rock - metamorphosed sandstone? - interbedded with very fine slates with disseminated **chalcopyrite**
32.0 - 32.5	Black medium grained crystalline rock and interbedded black thinly laminated slates, higher degree of metamophism, amphybolitic in nature, some disseminated **chalcopyrite**
Fine to coarse grained meta-sandstone, some slates with pyrite	
32.5 - 33.0	Black crystaline metamorphosed fine to medium grained sandstones with shales, original fabric all but lost? - sandstones are amphybolitic in form with shales altered to thinly laminated slates - increased metamorphism with increased disseminated **pyrite** content
33.0 - 33.5	Grey to dark grey fine to coarse grained recrystalised quartzitic sandstone with pyroxene? cement - almost completely altered, some disseminated **chalcopyrite**, few thinly laminated black slates
33.5 - 34.0	Dark grey to grey medium to coarse grained meta sandstone with disseminated chalcopyrite with interbedded fine grained thinly laminated slates
Fine to medium grained meta-sandstone, some slates with pyrite	
34.0 - 34.5	Dark grey fine to medium grained **pyritic** metasandstones with some black slates
34.5 - 35.0	Dark grey fine to medium grained **pyritic** metasandstones with increased black slates
35.0 - 35.5	Dark grey fine to medium grained **pyritic** metasandstones with some black slates, some disseminated **copper pyrite** and silvery sulphides along fracture
Medium to coarse grained meta-sandstone with slatey siltston and mudstone	
35.5 - 36.0	Grey to dark grey medium to coarse grained crystalline rock, metasandstone,

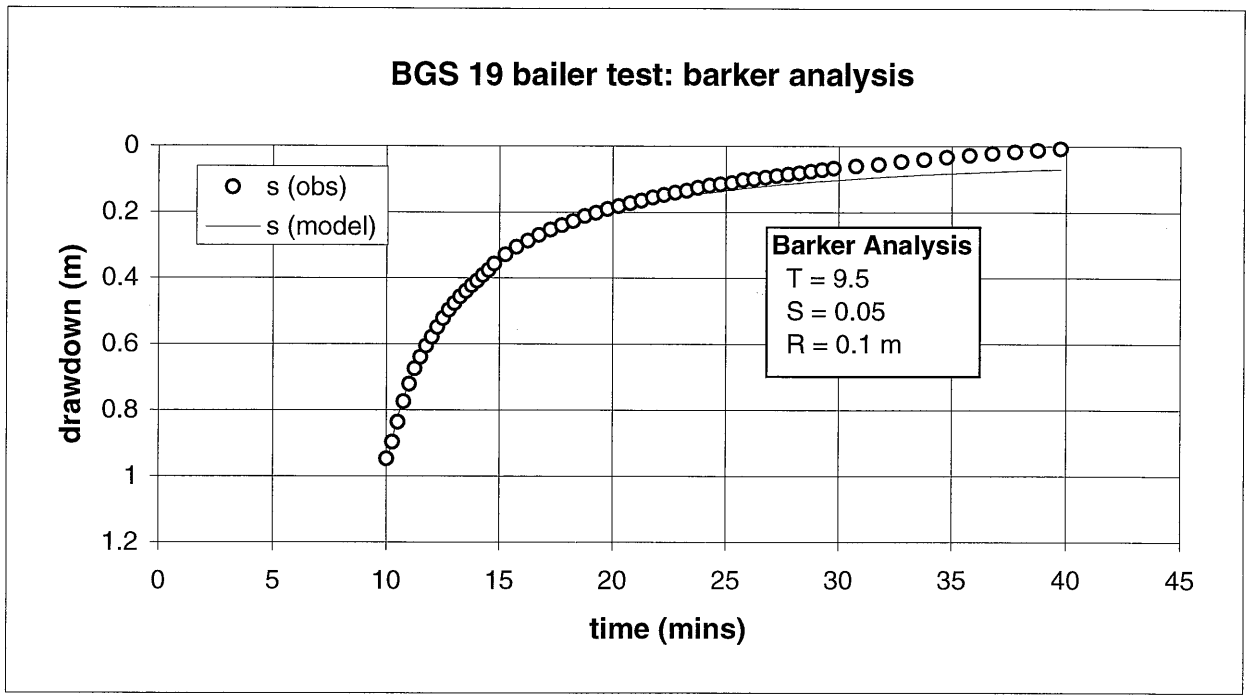
	interbedded with black to dark grey slatey metamudstones and siltstones
36.0 - 36.5	Grey to dark grey medium to coarse grained crystalline rock, metasandstone, interbedded with black to dark grey slatey metamudstones and siltstones, some brown weathered elongate cleavage planes, slates are very **pyritic** in parts
Fine to medium grained meta-sandstone with slatey mudstone	
36.5 - 37.0	Dark grey to grey fine to medium grained metasandstones interbedded with black slatey mudstones weathered orange in parts
37.0 - 37.5	Dark grey to grey fine to medium grained metasandstones interbedded with black slatey mudstones weathered orange in parts
Slatey mudstone with fine to coarse grained meta-sandstone	
37.5 - 38.0	Mainly black slatey shaley mudstones, fairly hard with subordinate fine to coarse metasandstone bands
Metamorphosed siltstone and fine grained sandstone, some chalcopyrite	
38.0 - 38.5	Black to dark grey metamorphosed siltstones to fine grained sandstones, some disseminated **copper pyrite**

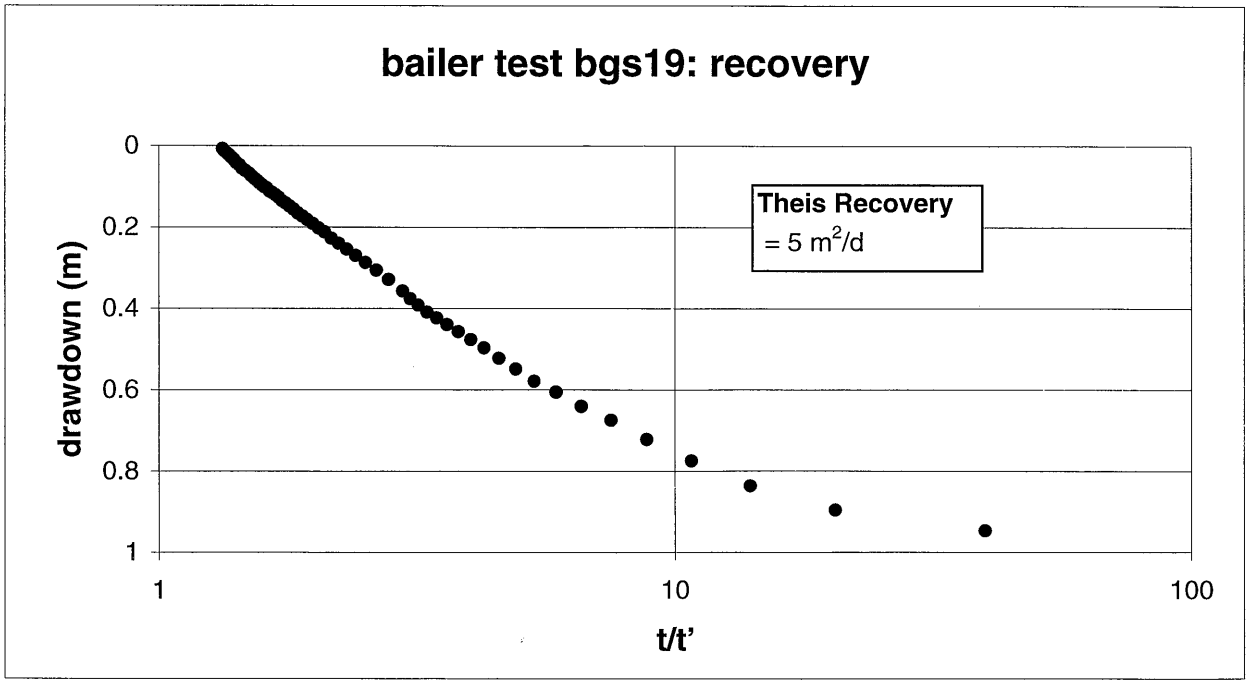
Annex 4: Pump test data

BGS19: bailer test

date: 18/03/98
casing: 0.6 m
rwl: 7.353 m
No bails: 35
time: 9:46 mins = 0.3 l/s

BGS20 had pump test earlier in day
therefore BGS 19 recovering slightly

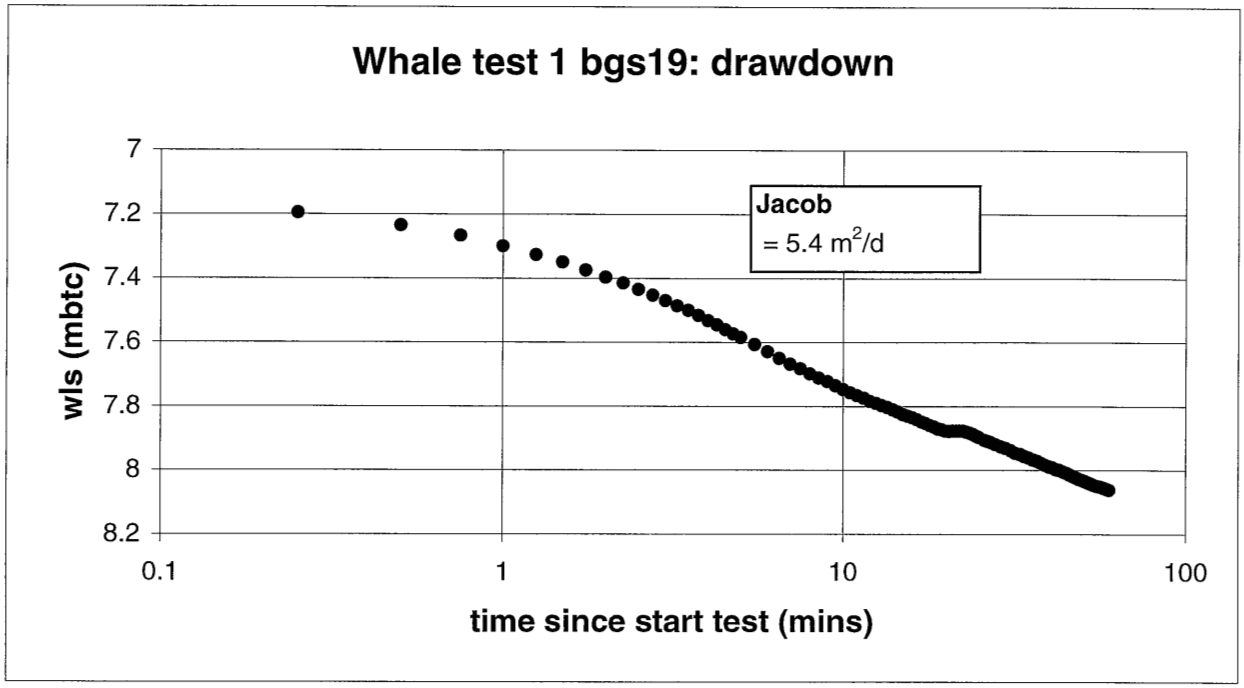


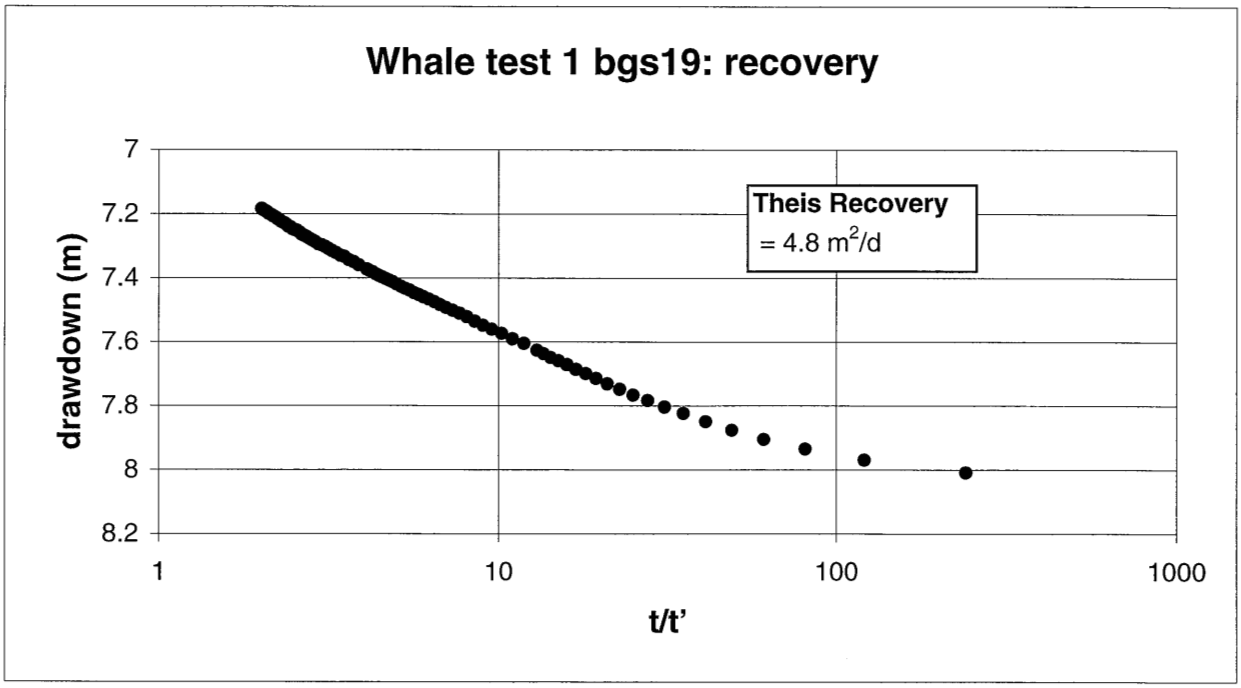


BGS19: whale test 1

date: 18/03/98
casing: 0.6 m
rwl: 7.128 m
time: 60 mins
p rate 0.16 - 0.155 l/s

BGS20 had pump test earlier in day
therefore BGS 19 recovering slightly
bailer test completed 2 hours previously
pump at 12 m

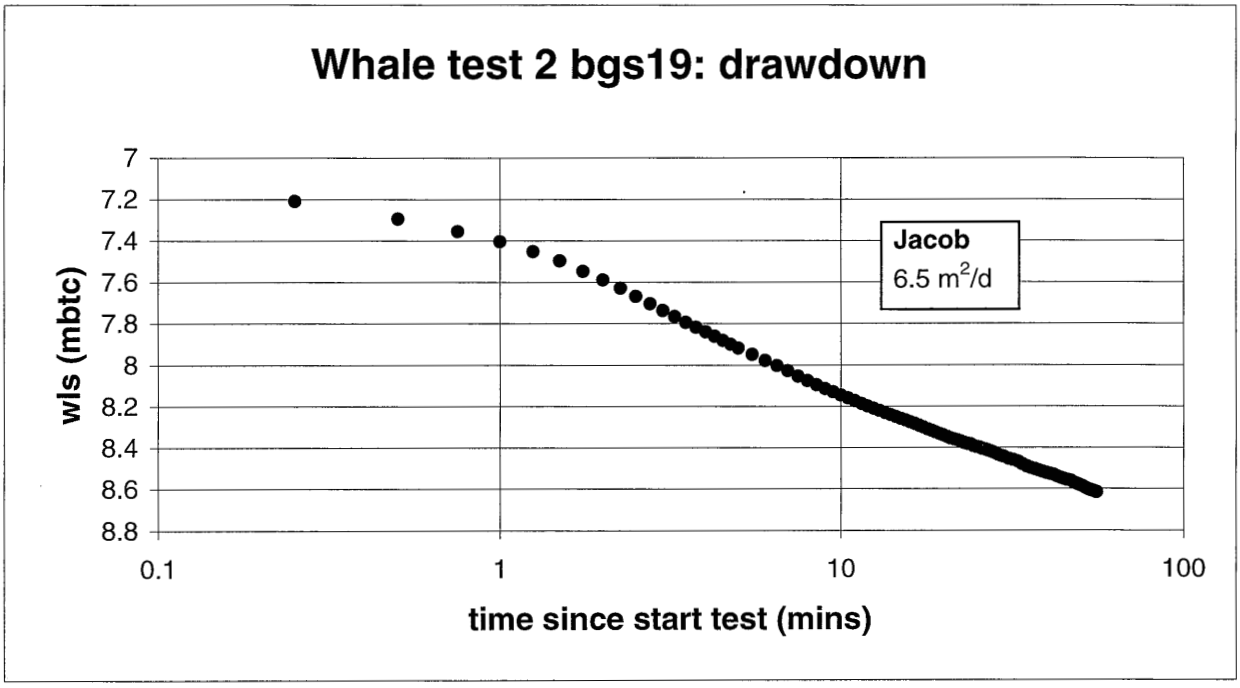


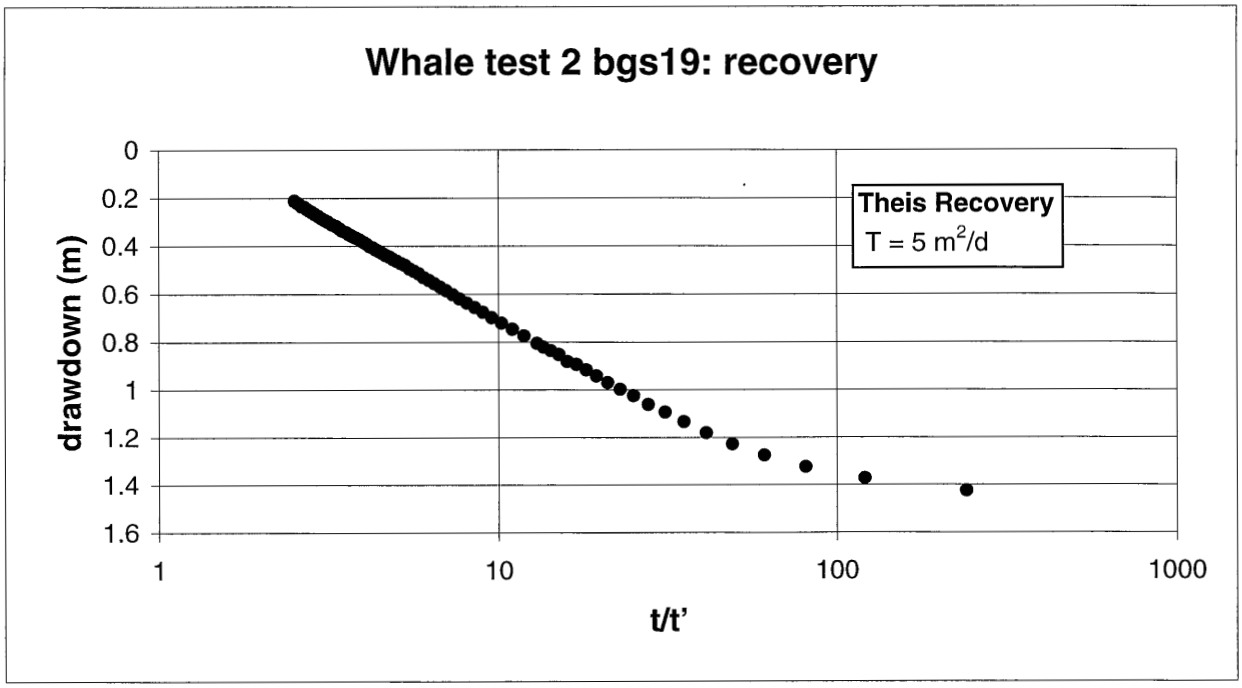


BGS19: whale test 2

date: 18/03/98
casing: 0.6 m
rwl: 7.145 m
time: 60 mins
p rate 0.28 - 0.25 l/s

BGS20 had pump test earlier in day
therefore BGS 19 recovering slightly
whale test 1 recovery just completed

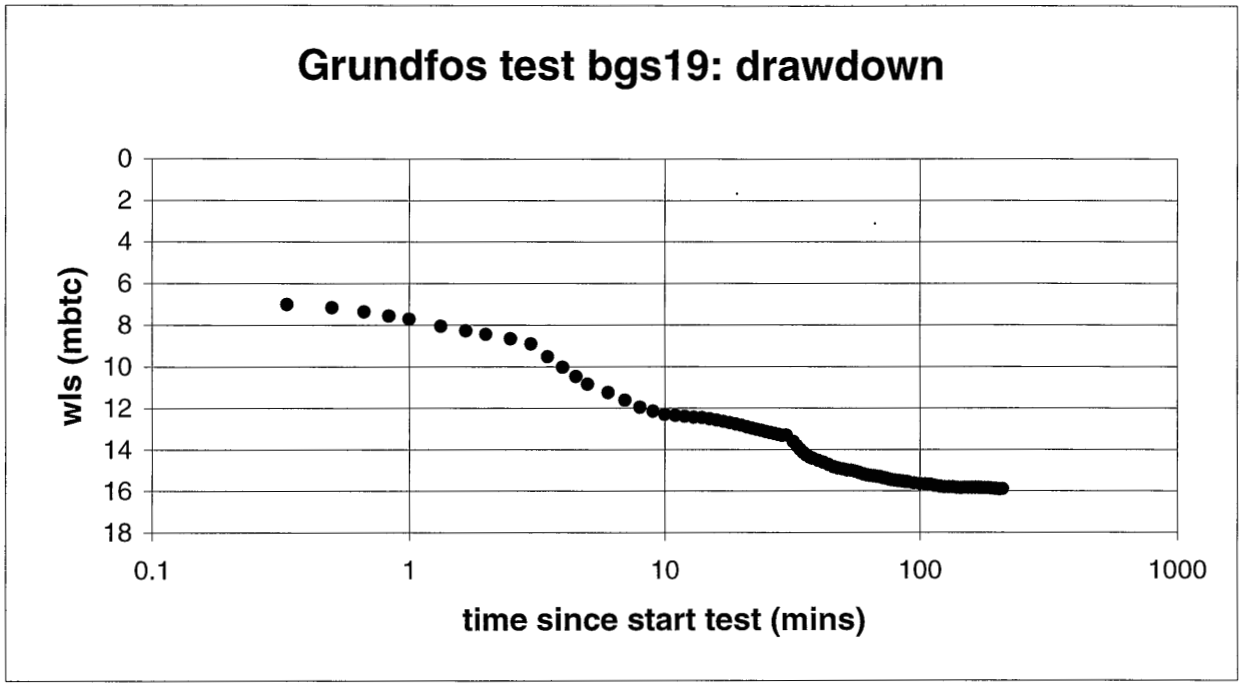


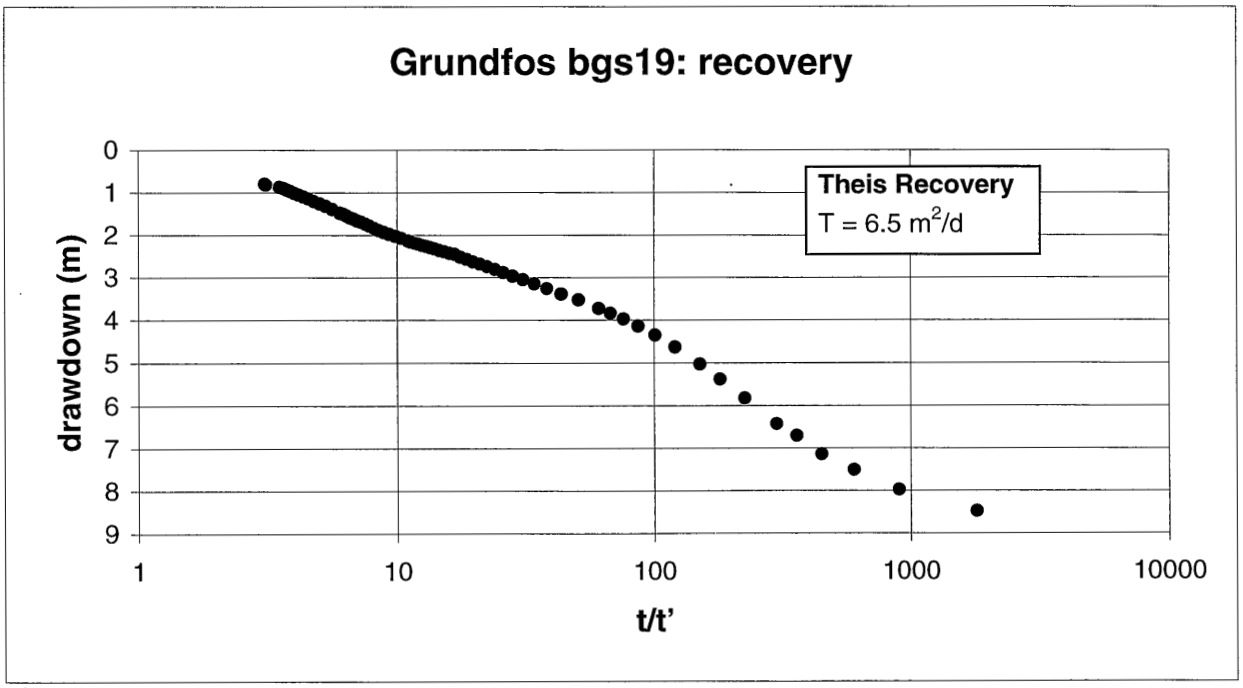


BGS19: grundfos

date: 21/03/98
casing: 0.6 m
rwl: 6.51 m
time: 300 mins
p rate 1.1 - 1 l/s

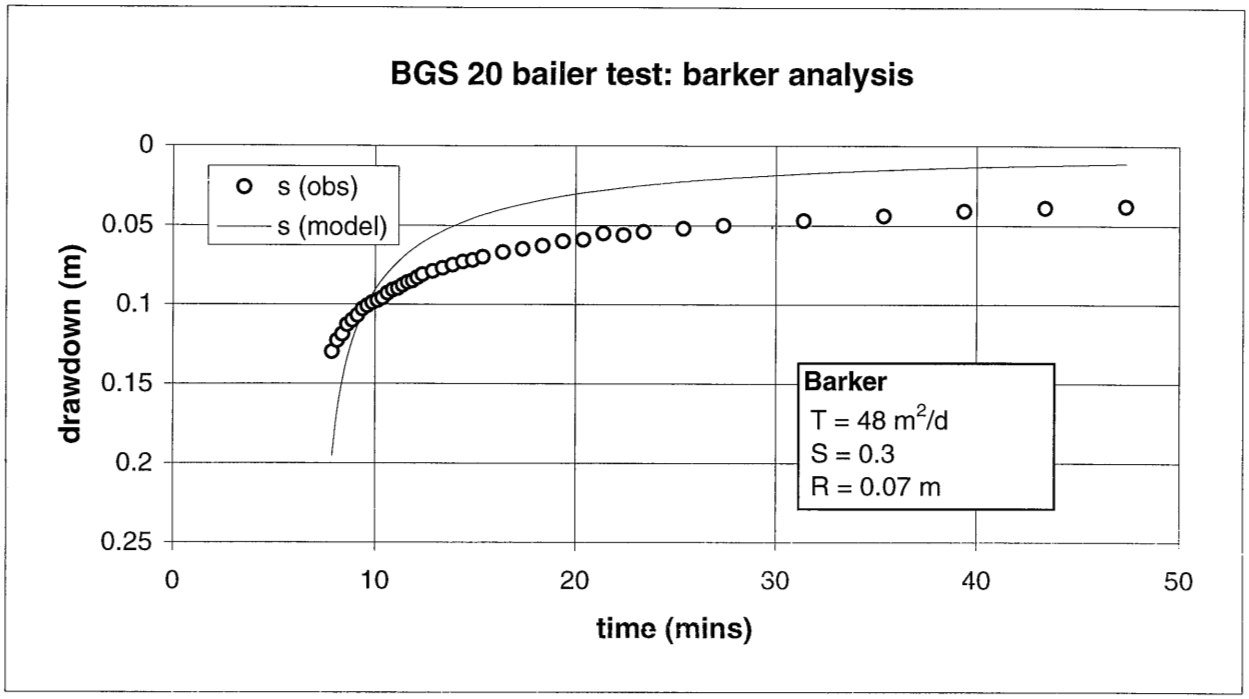
Problems with pump during drawdown

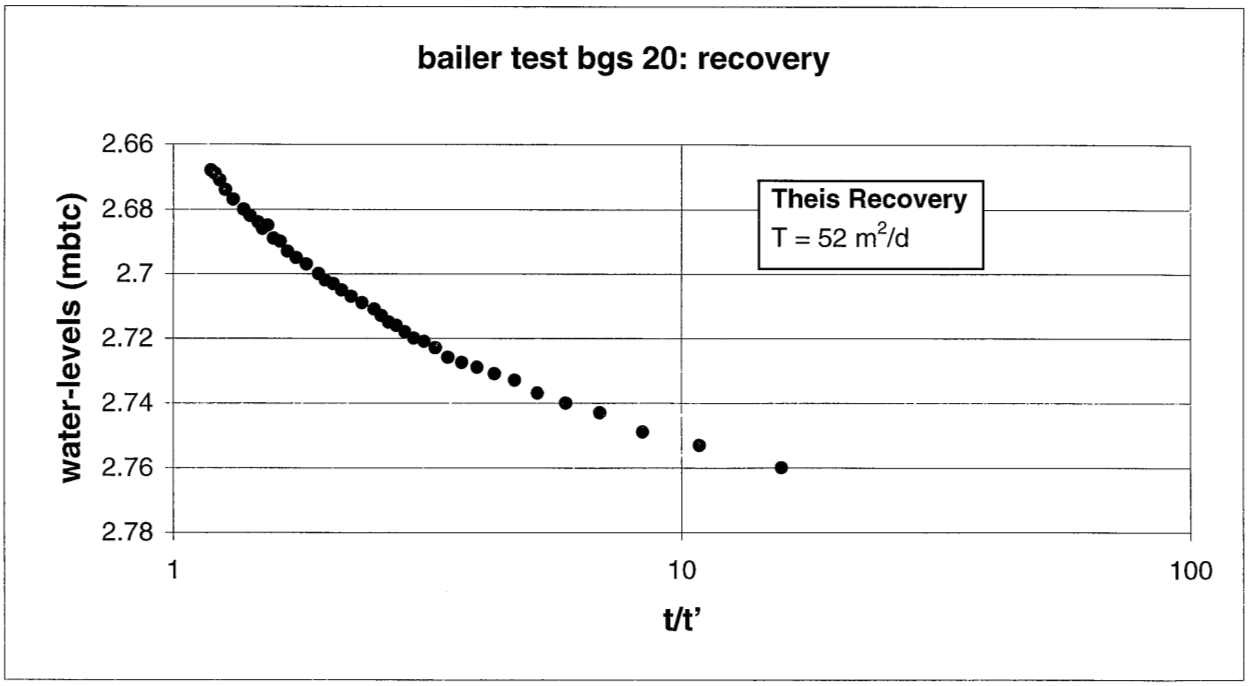




BGS20: bailer test

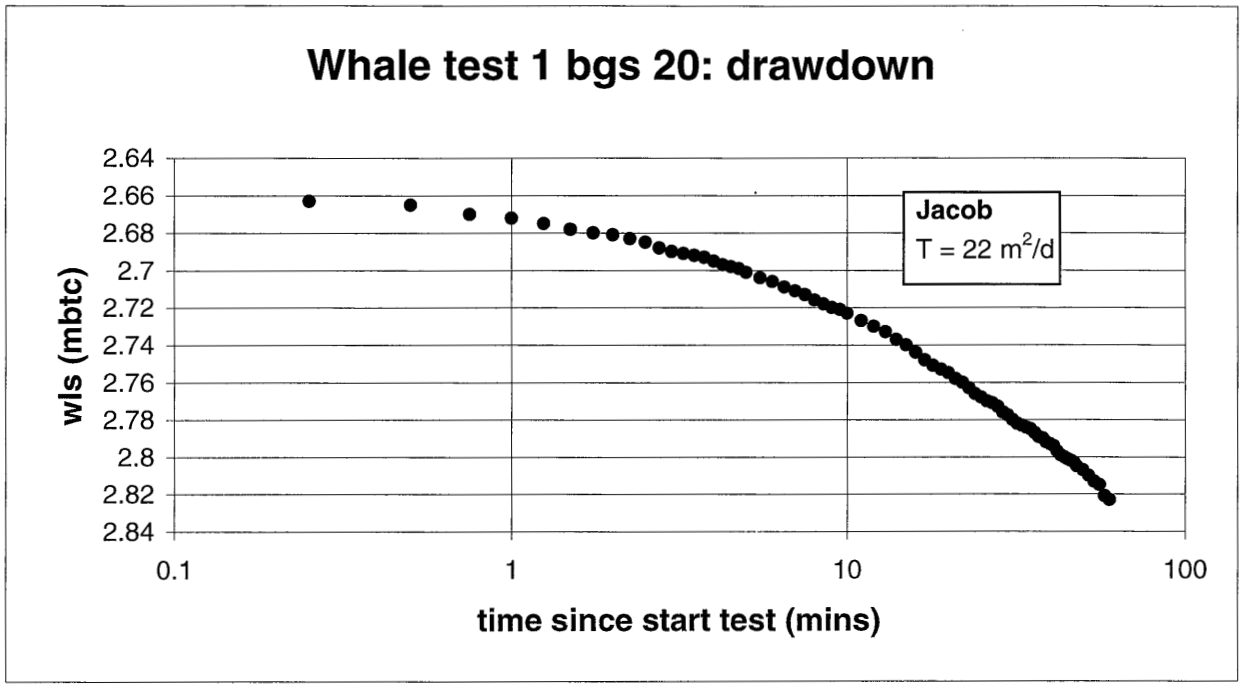
date: 19/03/98
casing: 0.25
rwl: 2.63 m
No bails: 41
time: 7:23 mins =0.46 l/s

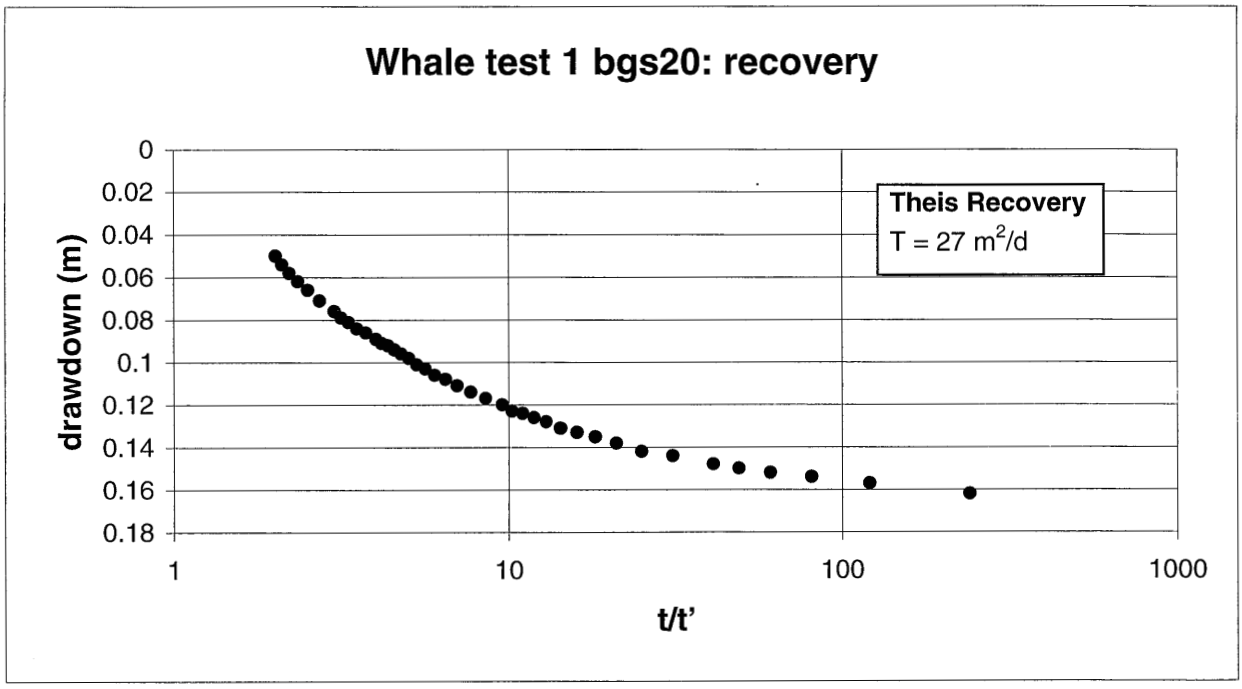




BGS 20: whale test 1

date: 19/03/98
casing: 0.25 m
rwl: 2.645 m
time: 60 mins
p rate 0.19 l/s

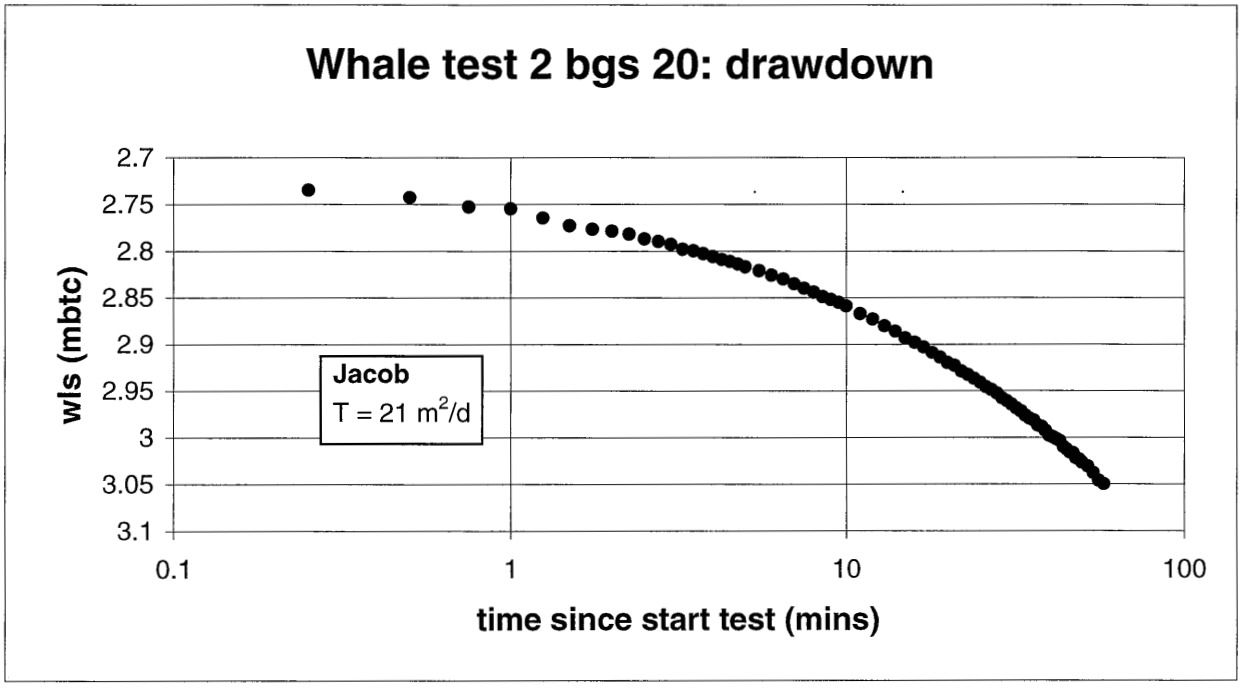


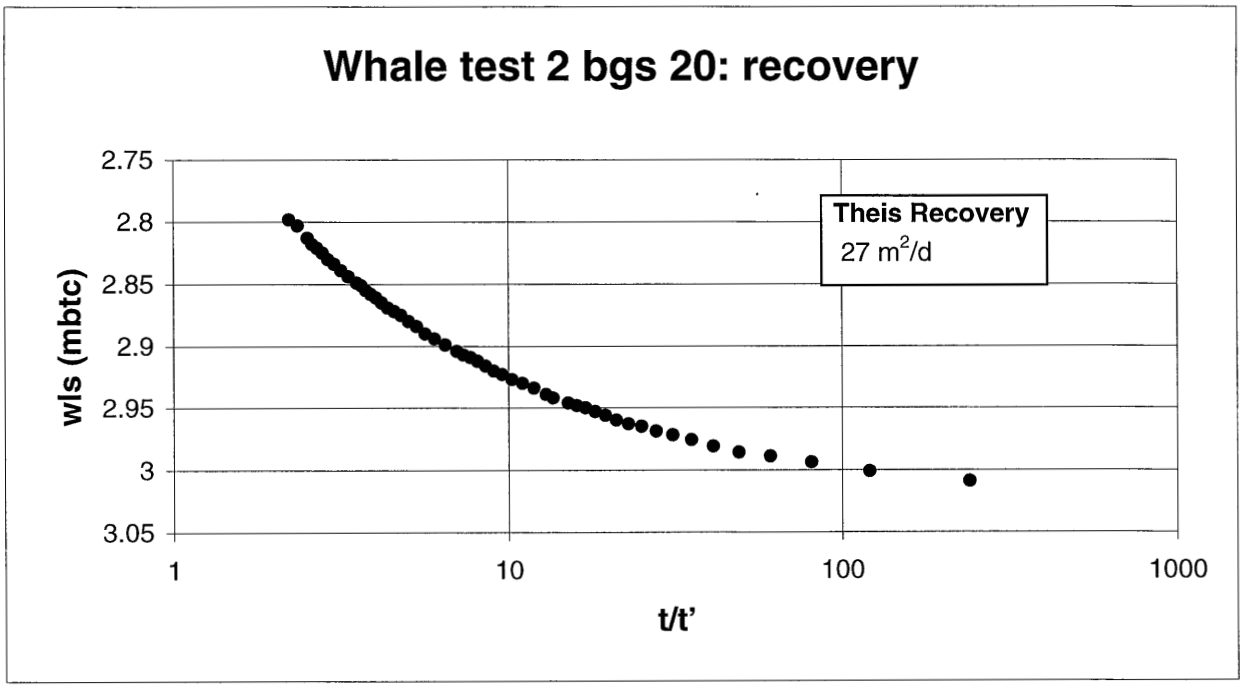


BGS 20: whale test 2

date: 19/03/98
casing: 0.25 m
rwl: 2.695 m
time: 60 mins
p rate 0.405 l/s

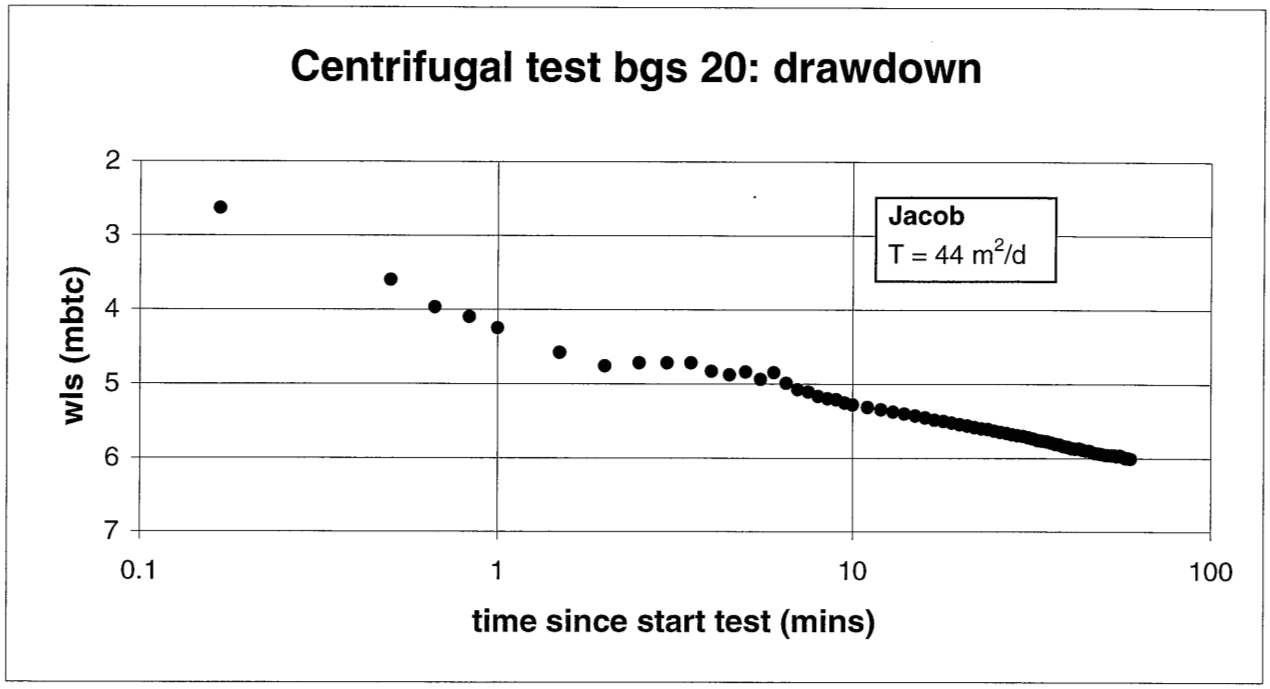
test carried out after Whale 1 recovery

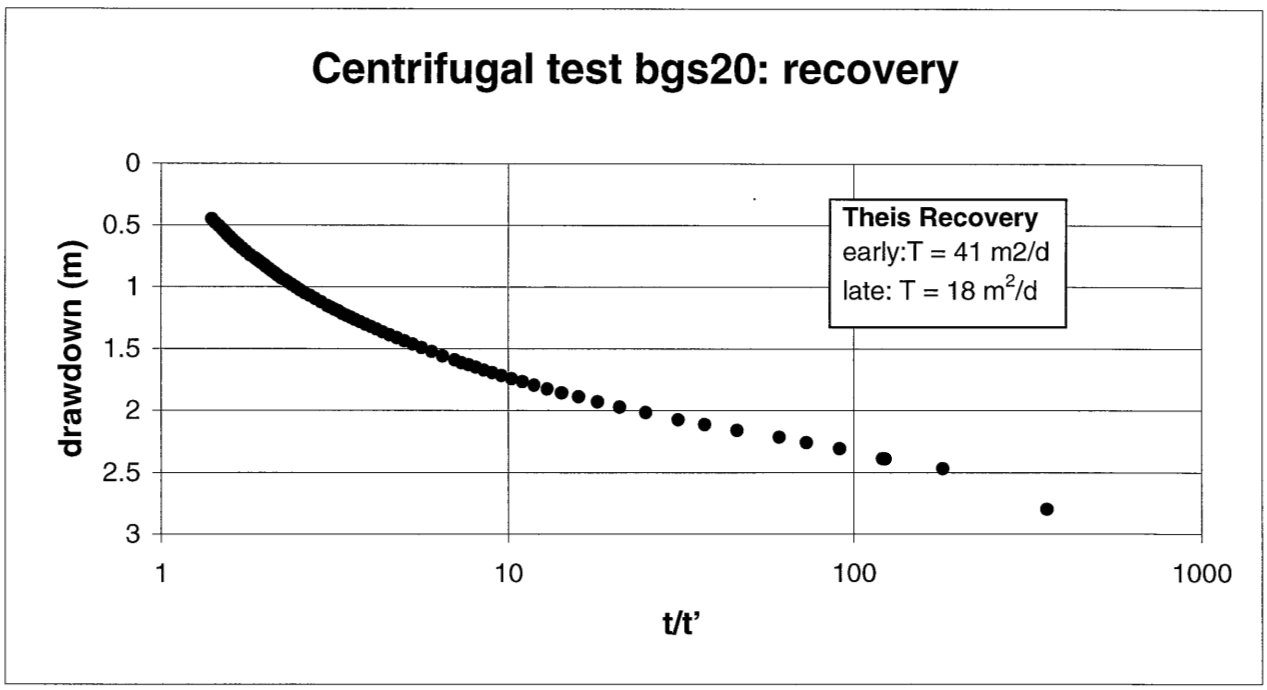




BGS 20: centrifugal

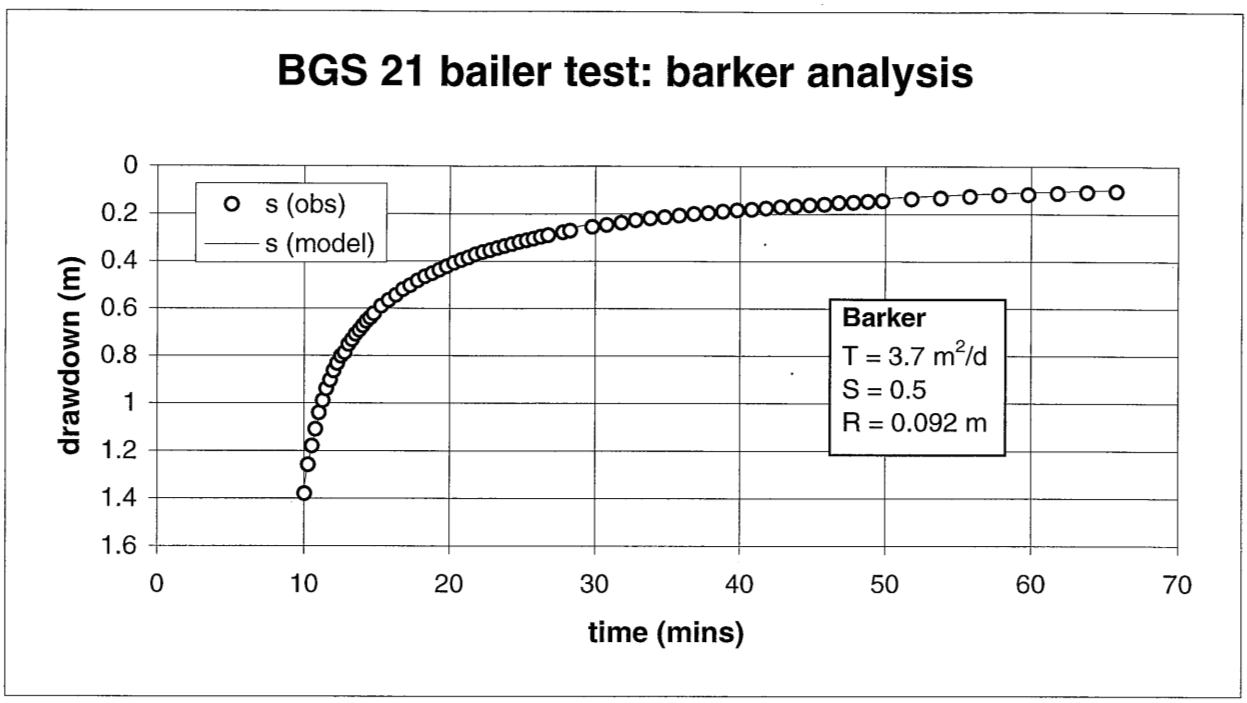
date: 18/03/98
casing: 0.25 m
rwl: 2.61 m
time: 60 mins
p rate 3.2 - 2.6 l/s average 2.9 l/s

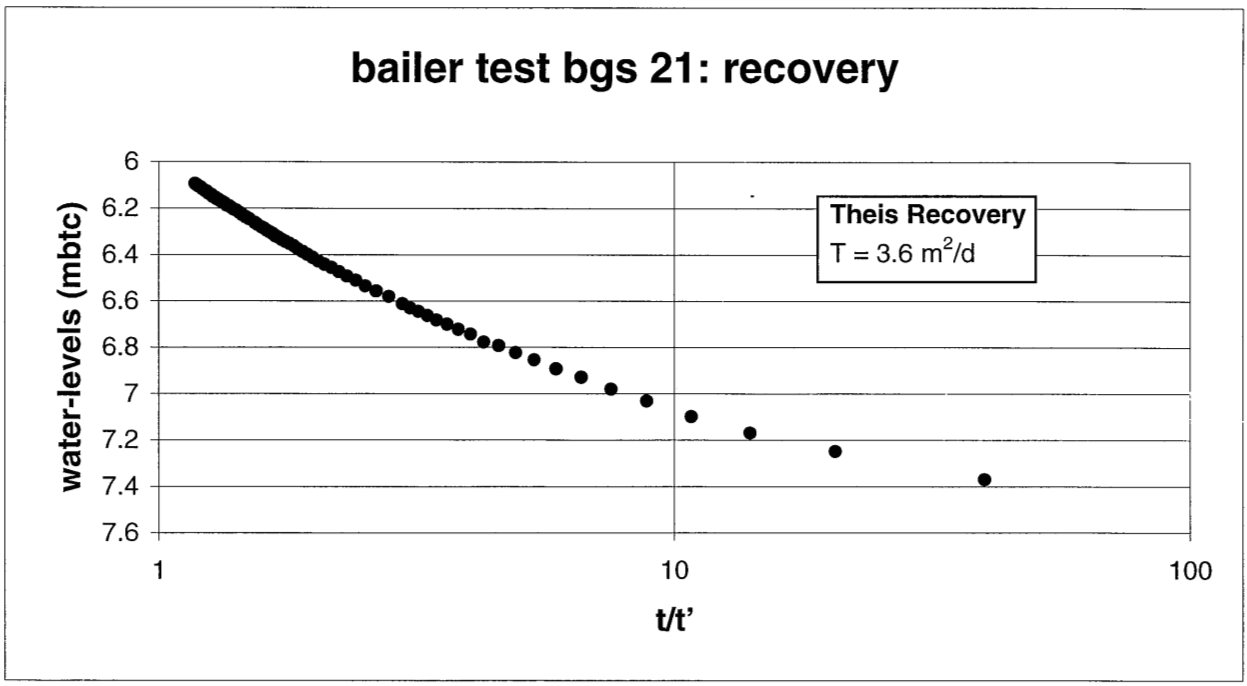




BGS 21: bailer test

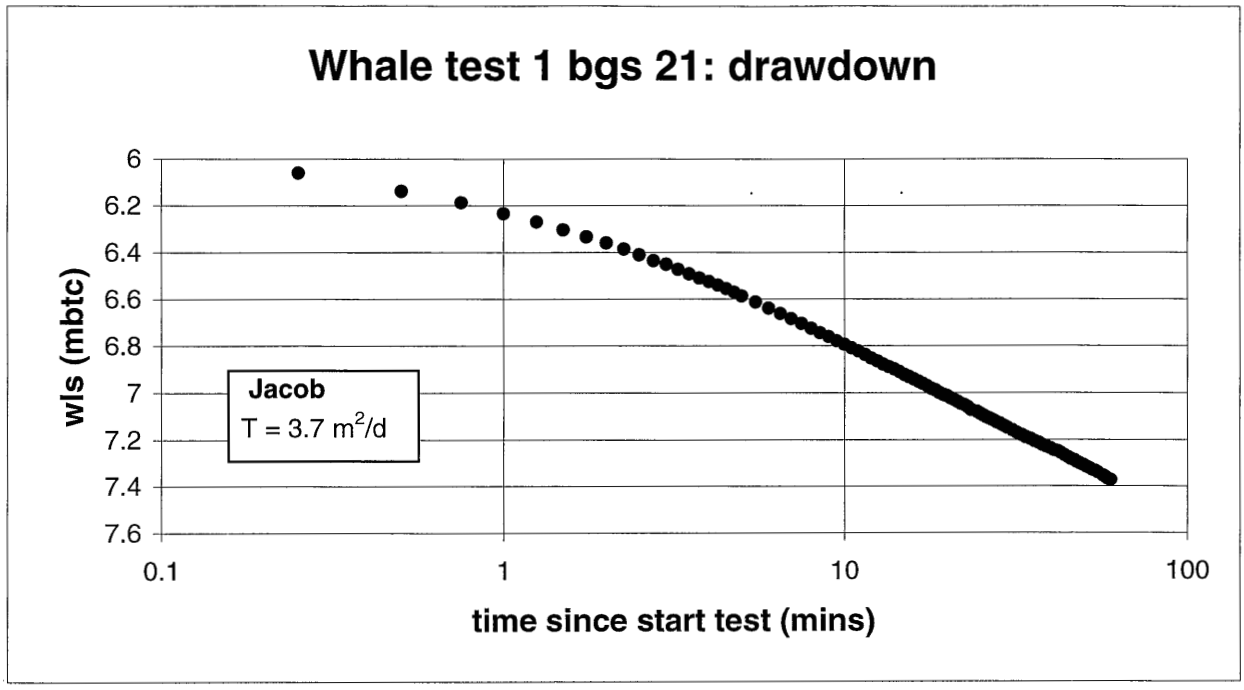
date: 18/03/98
casing: 0.5 m
rwl: 5.99 m
No bails: 38
time: 9:48 mins =0.32 l/s

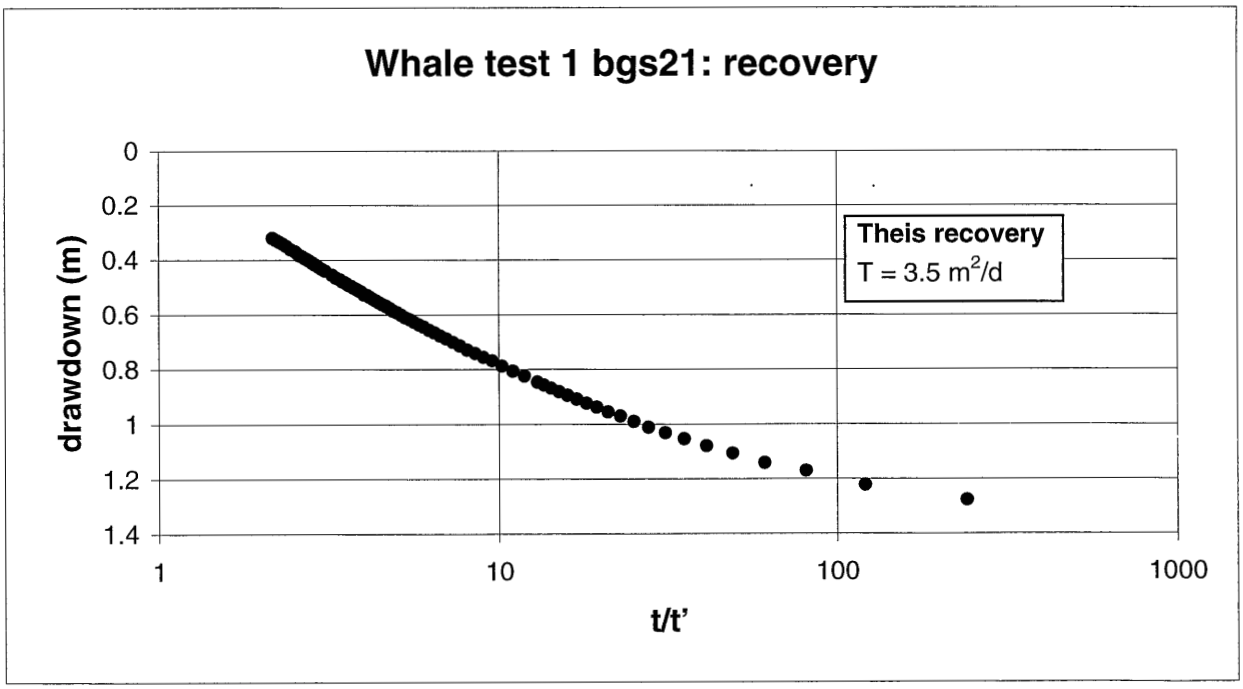




BGS 21: whale test 1

date: 19/03/98
casing: 0.5 m
rwl: 5.983 m
time: 60 mins
p rate 0.17 l/s

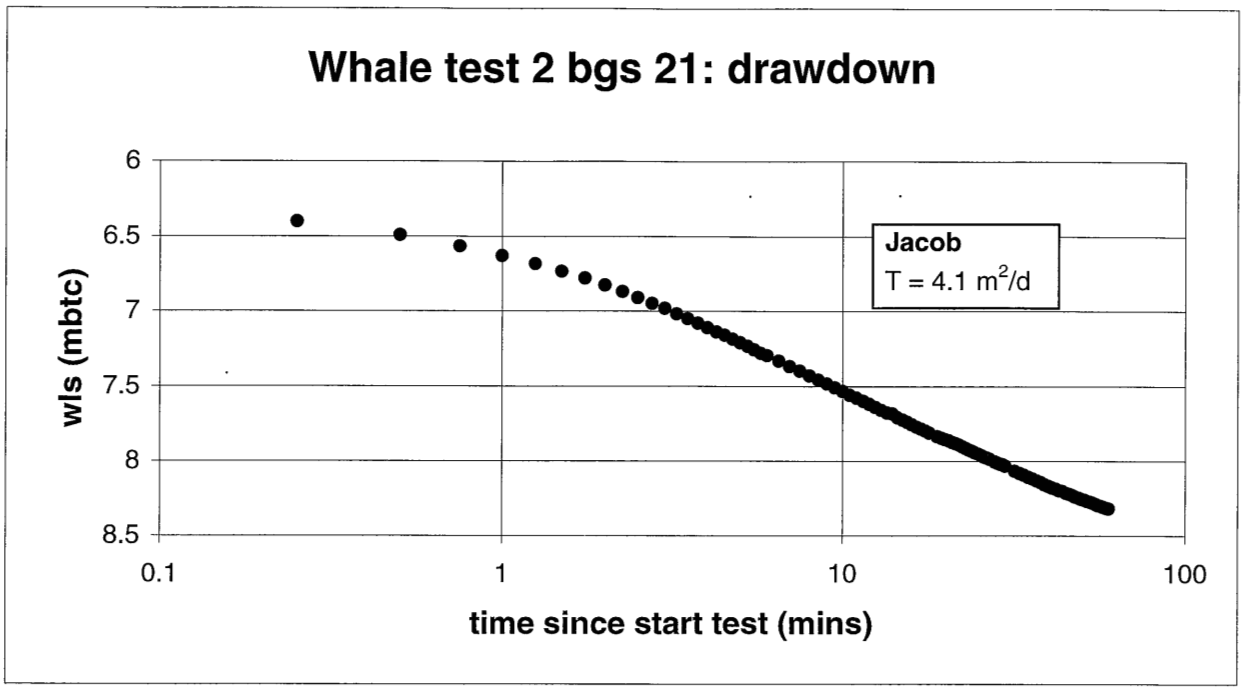


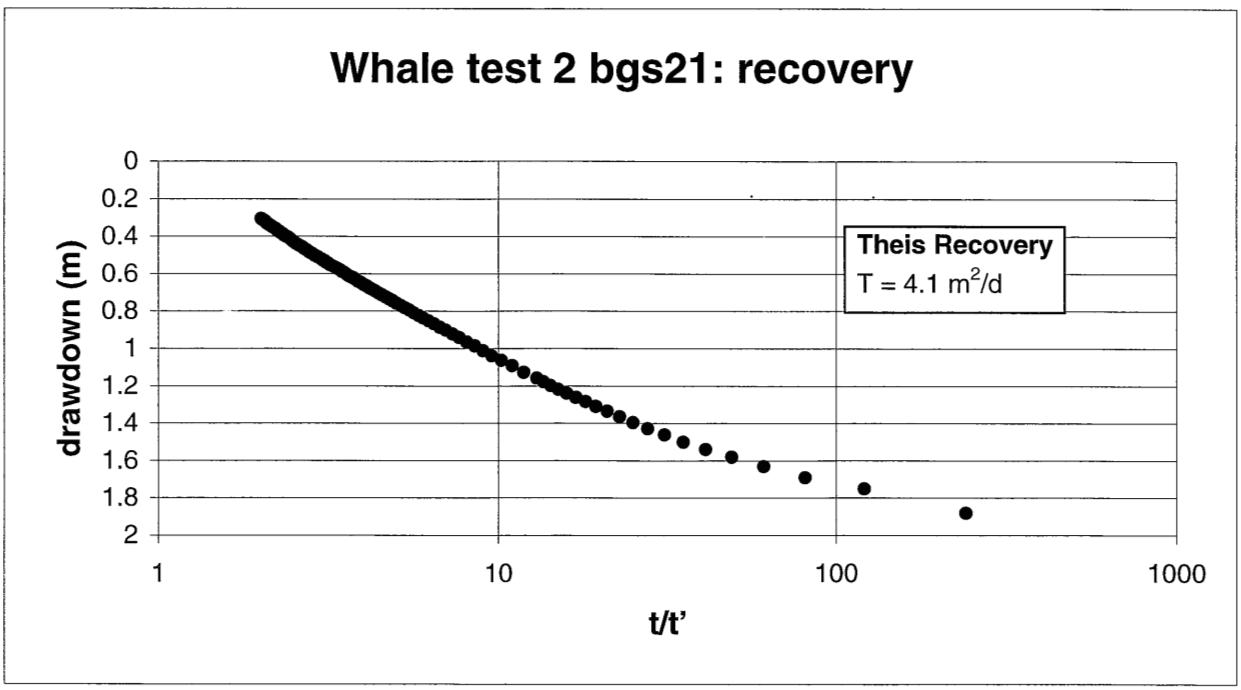


BGS 21: whale test 2

date: 19/03/98
casing: 0.5 m
rwl: 6.218 m
time: 60 mins
p rate 0.29 - 26 l/s (weighted average = 0.27 l/s)

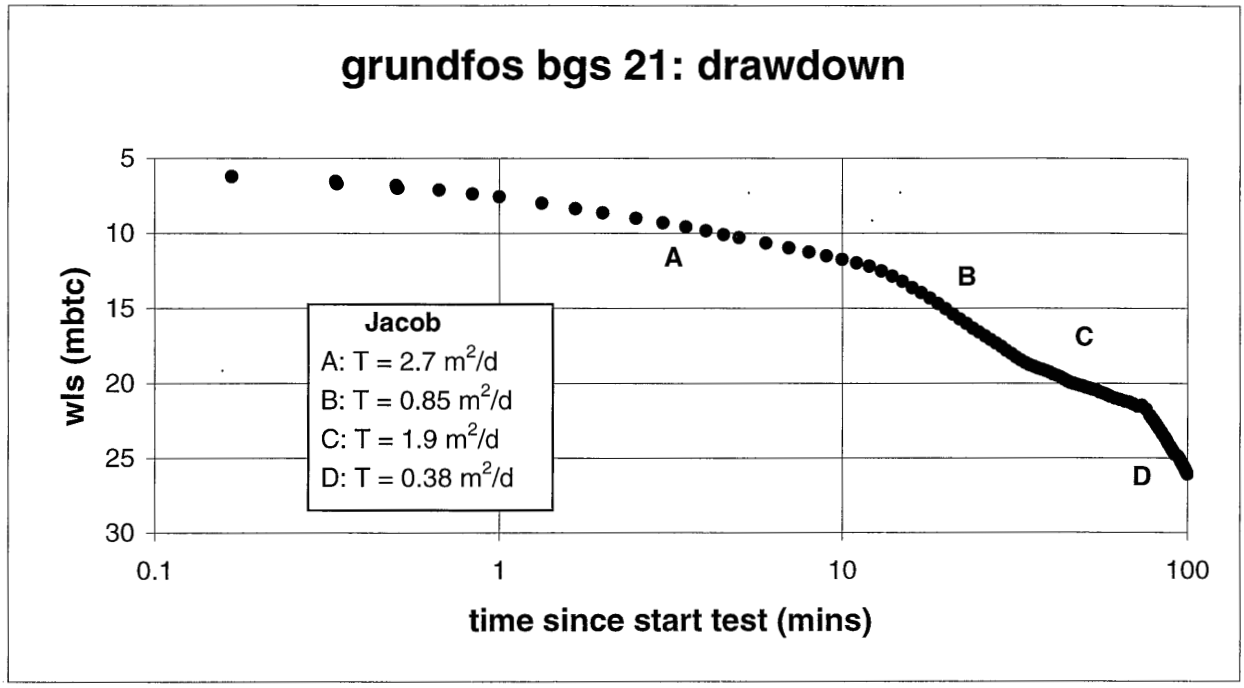
test started 85 mins after end of Whale test 1

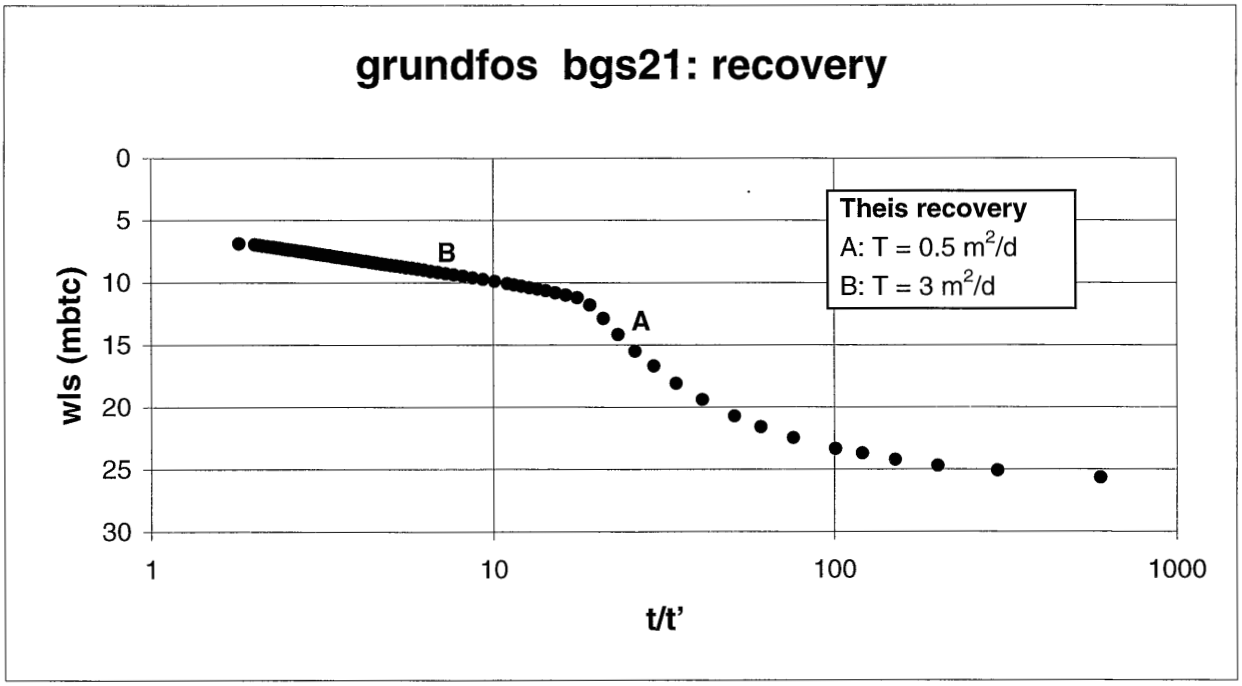




BGS 21: grundfos test

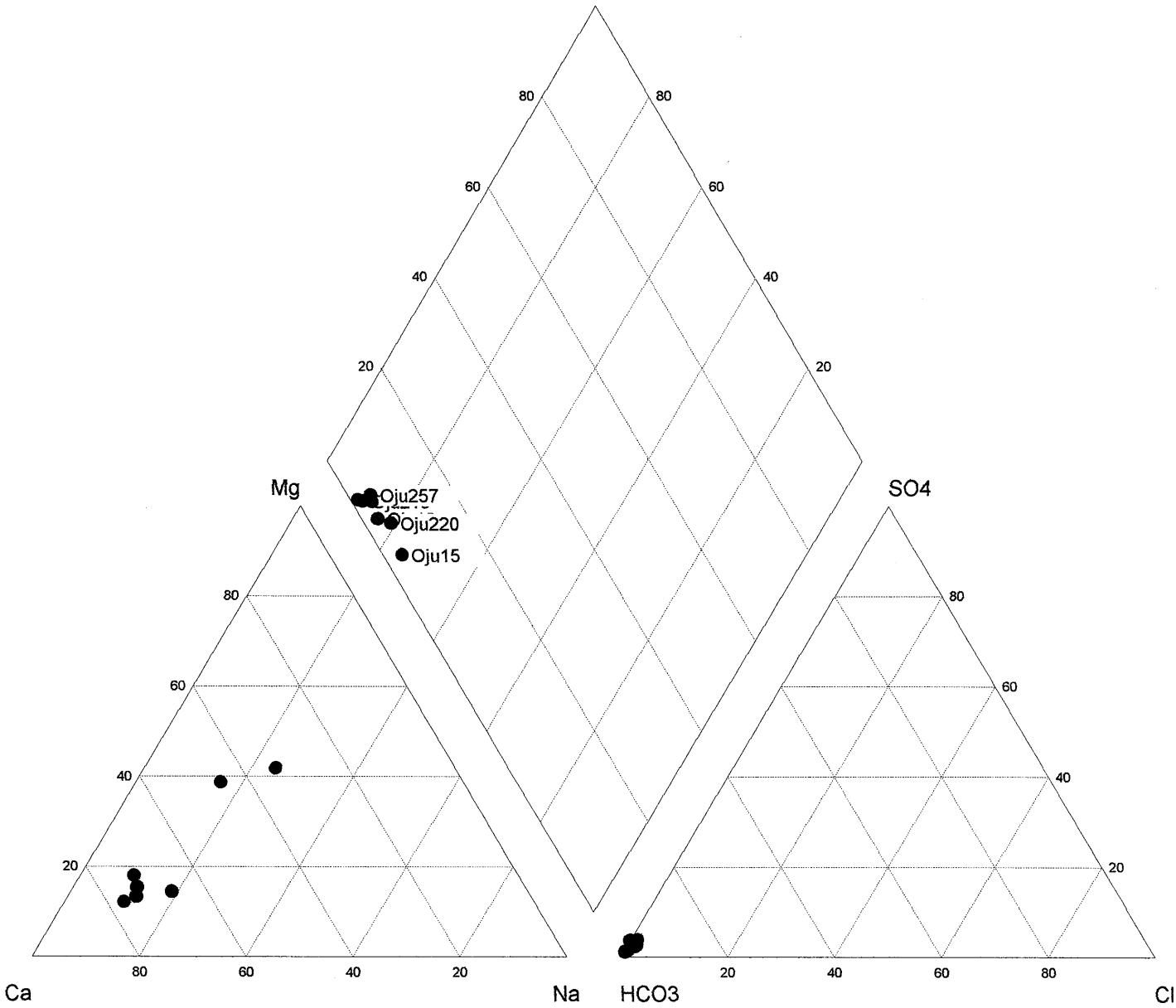
date: 22/03/98
casing: 0.5 m
rwl: 5.66 m
time: 100 mins
p rate 0.97 - 0.71 l/s (weighted average = 0.85 l/s)





Annex 5: Water quality data

Groundwater Chemistry - Oyinyi



Oyinyi Iyechi

Jan-Apr 1998

Easting	Northing	sample ID No	Bh No	pH	Temp DegC	Cond microS/cm	HCO3 mg/l	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	SO4 mg/l	Cl mg/l
8.506	6.804	Oju12	Ohoho	6.4	31.3	173	107	6.6	0.4	16.4	8.5	1.9	0.6
8.505	6.8	Oju13	Ohoho	6.93	29.6	620	402	19.9	0.4	100	11	7.8	3.6
8.495	6.793	Oju14	Ohoho	7.1	29.4	662	410	17.3	0.5	108	16.4	3.9	0.6
8.46	6.791	Oju15	Ameka	7.2	30.2	204	73	6.2	0.4	7.4	5.6	2.2	0
8.452883	6.8165	219	BGS21	6.68	29	588	358	16.2	0.8	97.8	9.4	4.5	
8.448317	6.80465	220	BGS20	7.07	28.8	699	410	34.8	0.9	107	14.1	13.1	
8.449233	6.813483	257	BGS19	6.93	29.2	532	319	15.2	1.5	80.6	10.4	7	

sample ID No	NO3-N mg/l	Si mg/l	Sr mg/l	Ba mg/l	Li mg/l	B mg/l	Fe Total mg/l	Mn mg/l	I mg/l	F mg/l	Br mg/l
Oju12		15.3	0.117	0.021			0.5	0.118	0.0026	0.2	0.003
Oju13		22.5	0.599	0.045	0.031		1.61	0.67	0.0028	0.29	0.009
Oju14		18.2	0.775	0.083	0.021		1.68	0.094	0.0023	0.21	0.004
Oju15		11.1	0.033	0.009	0.009		0.16	0.036	0.0019	0.16	0.002
219		18.4	0.866	0.026	0.038	-0.03	0.14	0.395	0.0051		
220		17.1	1.57	0.166	0.011	-0.03	1.47	0.04	0.0077		
257		18	0.441	0.015	0.014	-0.03	0.16	0.763	0.0051		